FEB 28 1960

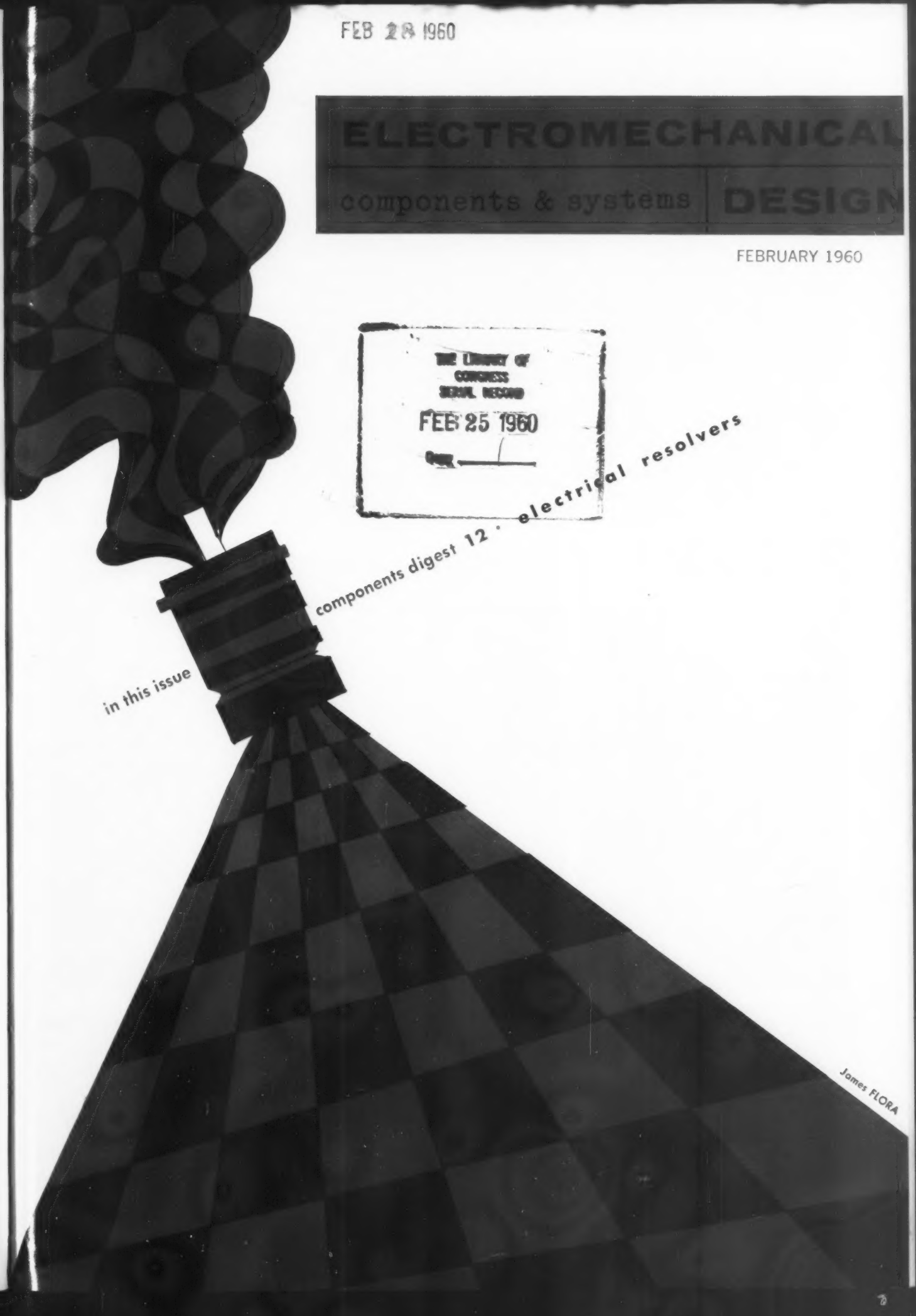
ELECTROMECHANICAL components & systems DESIGN

FEBRUARY 1960

THE LIBRARY OF CONGRESS SERIAL RECORD
FEB 25 1960

components digest 12 · electrical resolvers

in this issue



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SERIAL BINARY (LINEAR)	707 713 717 719	7 bits (128) 13 bits (8192) 17 bits (131,072) 19 bits (524,288)	128 128 128 128
BINARY (SIN-COS)	757* 758*	7 bits per quadrant 8 bits per quadrant	512 1024
BINARY CODED DECIMAL	723 through 735	2,000 through 360,000	200
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CIRCLE NO. 21 ON INQUIRY CARD

FEB 18 1960

ELECTROMECHANICAL
components & systems DESIGN

The Sourcebook of Design Ideas in Applied Electromechanics

FEBRUARY 1960 . VOL. 4 NO. 2

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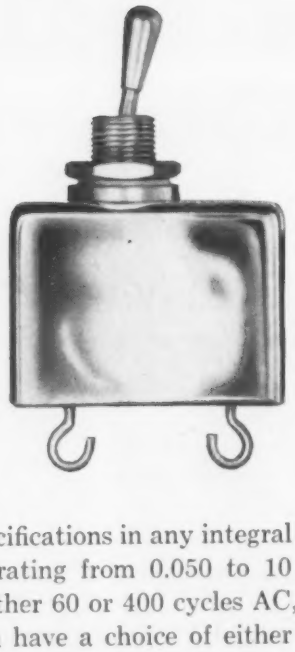
ACTUAL SIZE



This is the actual size of Heinemann's new sub-miniature circuit breaker, the SM3. Hermetic seal and all, it weighs no more than a bantam 2.1 ounces. It is magnetically actuated, therefore does not require de-rating for high ambient temperatures. In fact, under extensive environment-testing, the breaker has demonstrated excellent all-around operational stability. It will function properly on the tundra or in the tropics, will withstand the onslaughts of salt-sea atmosphere, sand, dust and high humidity. The SM3 is available to your specifications in any integral or fractional current rating from 0.050 to 10 amperes, at 110V, either 60 or 400 cycles AC, or 50V DC. And you have a choice of either fast or slow time delay, so that overload response can be matched closely to the operating characteristics of the protected equipment. If you have need of a rugged, compact circuit breaker "packaged" to go anywhere, you'd do well to give the SM3 some serious consideration. The facts and figures are presented for your review in Bulletin 3502. Write for a copy today.

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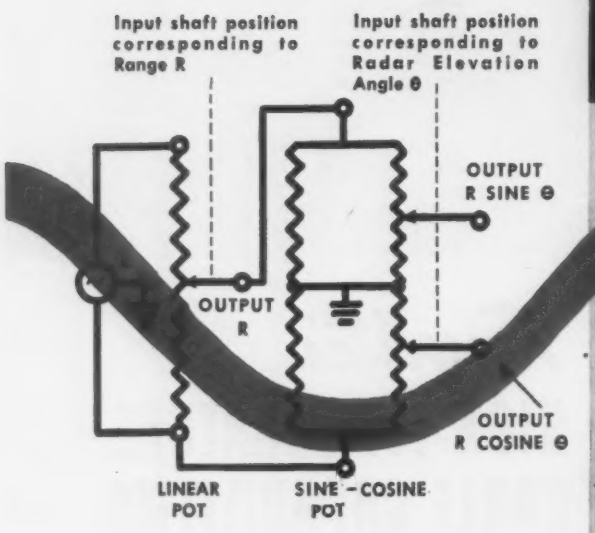
CIRCLE NO. 18 ON INQUIRY CARD

ON THE TARGET!

WITH C I C

SINE-COSINE FILM POTS

* 0.015% ACCURACY!
* INFINITE RESOLUTION!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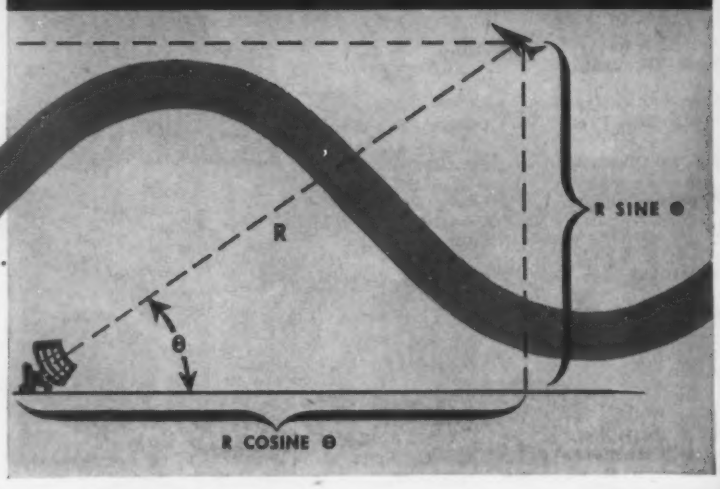
Input shaft position corresponding to Radar Elevation Angle θ
OUTPUT R SINE θ
OUTPUT R
OUTPUT R COSINE θ
LINEAR POT
SINE – COSINE POT



COMPARE SYSTEMS ERROR YOURSELF!

Typical example of Radar Tracking System Problem: To accurately locate target	Error with Wire-Wound Pots	Error with C.I.C. Film Pots
Range to Target: 50,000 yards Radar Elevation Angle: 45°	Quadrature due to Inductance of Windings (@ 1000 cps) . . . 35 Resolution . . . . . 30 Linearity . . . . . 50 115 yds	Quadrature due to Inductance 0 Resolution . . . . . 0 Linearity . . . . . 8 8 yds

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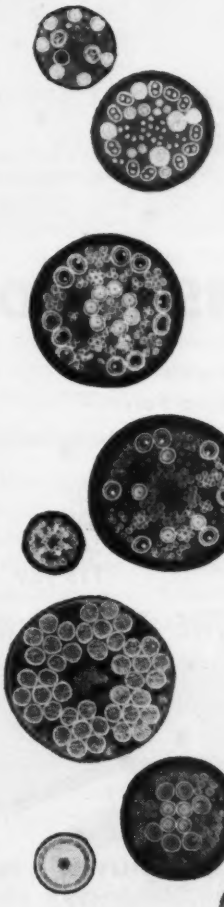

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* 0.015% ACCURACY!
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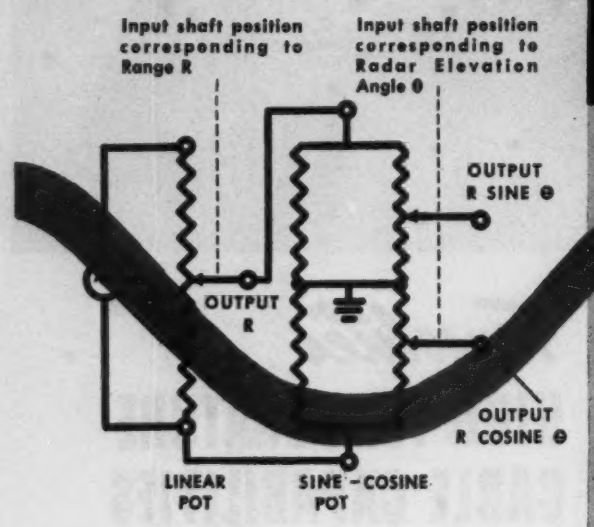
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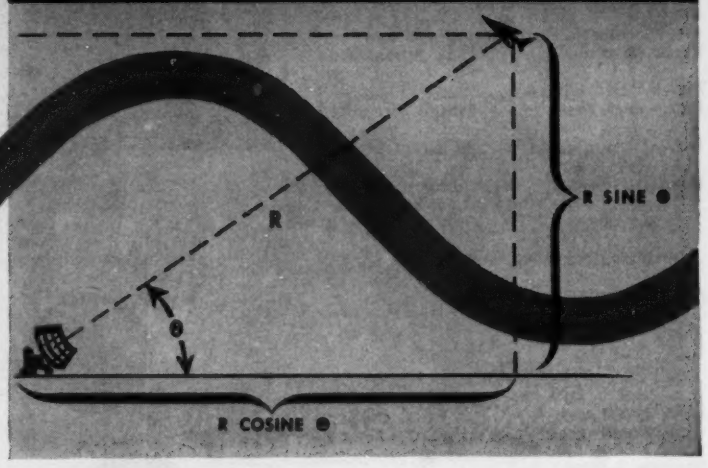

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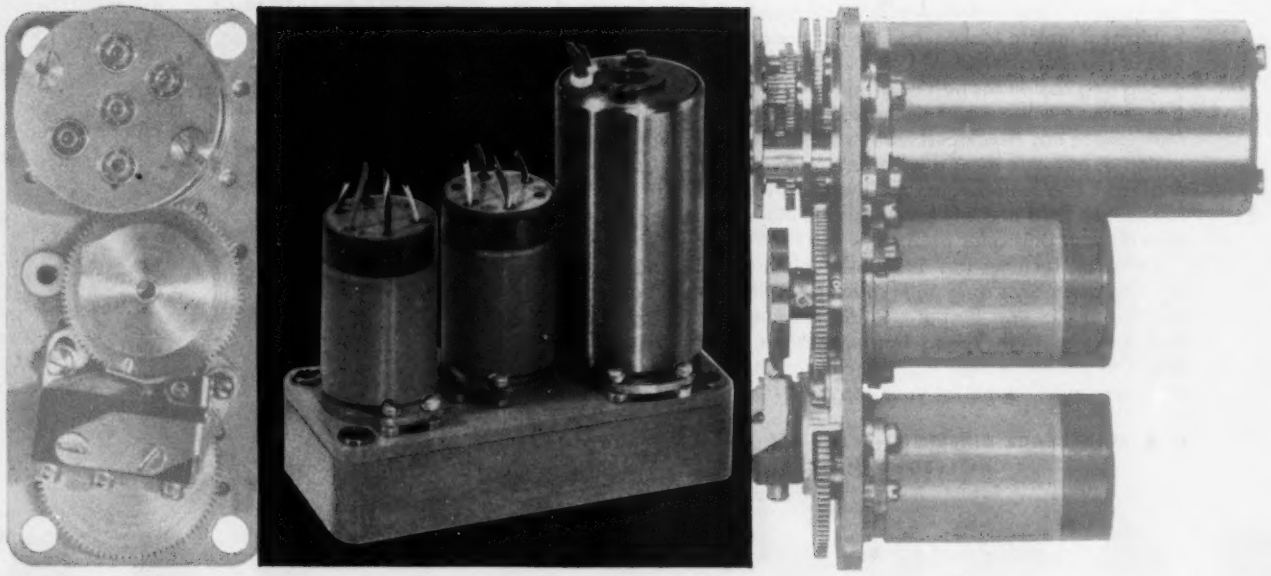

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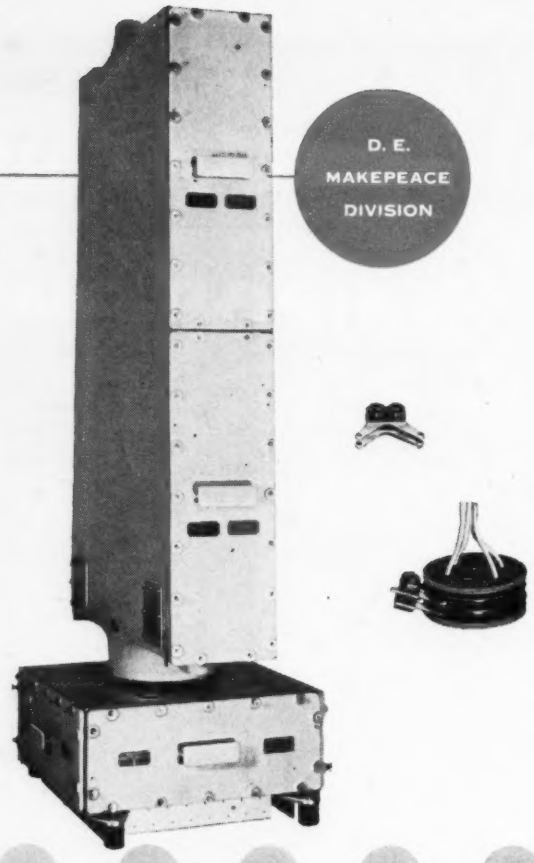

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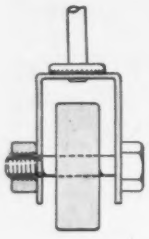

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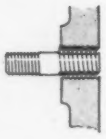
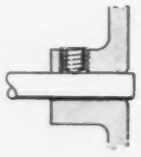


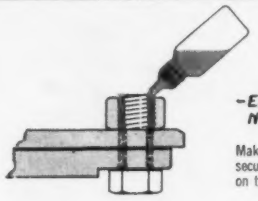
– ELIMINATES INTERFERENCE FIT

Locks studs securely . . . locking action develops after stud is in place . . . allows easy-driving Class 2 threads. End stripped threads, broken studs, damaged castings.



– ELIMINATES DOUBLE SET SCREWS, SELF-LOCKING SET SCREWS, JAM NUTS ON EXTENDED SET SCREWS OR STAKING

LOCTITE-treated set screws cannot vibrate loose . . . end nuisance service calls.

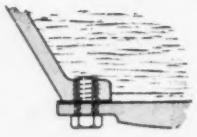


– ELIMINATES SELF-LOCKING NUT OR LOCK WASHER

Makes any nut a lock nut. Saves 40%-70%. Holds securely where lockwashers fail. Does not depend on tightening torque for locking action.

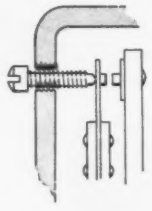
– ELIMINATES SPECIALS OR STAKING

Makes any threaded part self-locking.



– ELIMINATES BLIND HOLE TAPPING, SPECIAL LEAK-PROOF FASTENERS

LOCTITE locks and seals threaded parts against vibration and high-pressure fluids.



– ELIMINATES SELF-LOCKING SCREW OR JAM NUT

Get the right setting the first try . . . no backlash. LOCTITE provides the proper amount of drag to hold adjustment securely. Permits repeated adjustments.

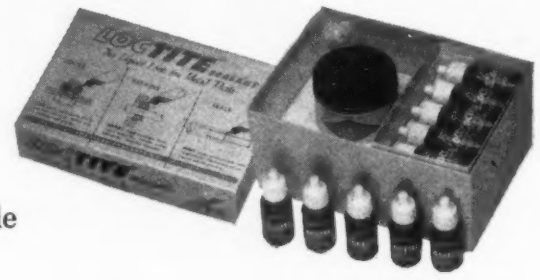
LOCTITE Sealant is easy to apply . . . simple to automate

Labor savings are obtained when several days supply of threaded parts are treated by tumbling with LOCTITE Sealant. Treated parts store for days, lock only when assembled. Smaller quantities may be tumbled by hand in polyethylene bags. Parts may be individually treated using applicator nozzle on LOCTITE bottle or by using continuous feed tube. Parts may be treated *after* assembly, LOCTITE wicks into threads by capillary action.

LOCTITE is a thin liquid that hardens into a tough heat and oil-resistant seal when confined between closely fitting metal parts. It requires no heating or mixing . . . does not air dry. LOCTITE comes fully prepared . . . stores for years . . . hardens only when treated parts are assembled. Ten grades provide any desired torque to all sizes and types of fasteners. LOCTITE-treated fasteners may be removed with ordinary tools . . . fasteners may be re-used.

LOCTITE Kit No. 10-10

Contains 10 grades of Loctite sealant specially put up to assist engineers in determining proper grade of Loctite in product development and for general experimental work. By selection of proper grade, the designer can apply a pre-determined amount of locking torque.



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ELECTRICAL INDUSTRIES *A Division of Philips Electronics, Inc* **MURRAY HILL, NEW JERSEY**

CIRCLE NO. 20 ON INQUIRY CARD

APPLIED CRYOGENICS

Superconductivity In Gyro Reduces Mechanical And Electrical Losses To "Almost Zero"

Disclosing an engineering development with kinship to perpetual motion, General Electric says it has successfully suspended a small metal body in a vacuum and has rotated it at high speed essentially without friction—made possible in part by "complete absence of measurable electrical losses." The development makes use of characteristics exhibited by certain metals and alloys which at extreme low temperatures become "superconductive."

Engineers at General Electric, employing these principles, have come up with a "cryogenic gyroscope." G. A. Hoyt, Ordnance Department general manager at Pittsfield, Mass., said the cryogenic gyroscope will be many times more accurate than the best conventional gyros because the general causes of unpredictable gyro error will have been either eliminated or reduced to negligible factors. Since the world of super-cold is a dead world where no chemical or organic change takes place, the sustained reliability of the cryogenic gyro will be vastly higher than that of conventional gyros.

The increased accuracy is seen resulting from elimination of mechanical bearings, reduction of friction and electrical losses "almost to zero" and the heightened dimensional stability induced by the extreme low temperatures. A navigation system containing a super-conductive gyroscope would permit a submarine or land vehicle to determine its exact position at any point on earth with a precision not otherwise possible except through time-consuming measurements. Such positioning would include highly accurate orientation to true north, necessary for the most exacting accuracy in missile firing.

"We can foresee applications for missile inertial guidance," Mr. Hoyt said, "that will improve our ability to place a payload where we want it, and space navigation systems that will help future astronauts find their way around the universe."

Circle No. 114 on Inquiry Card.

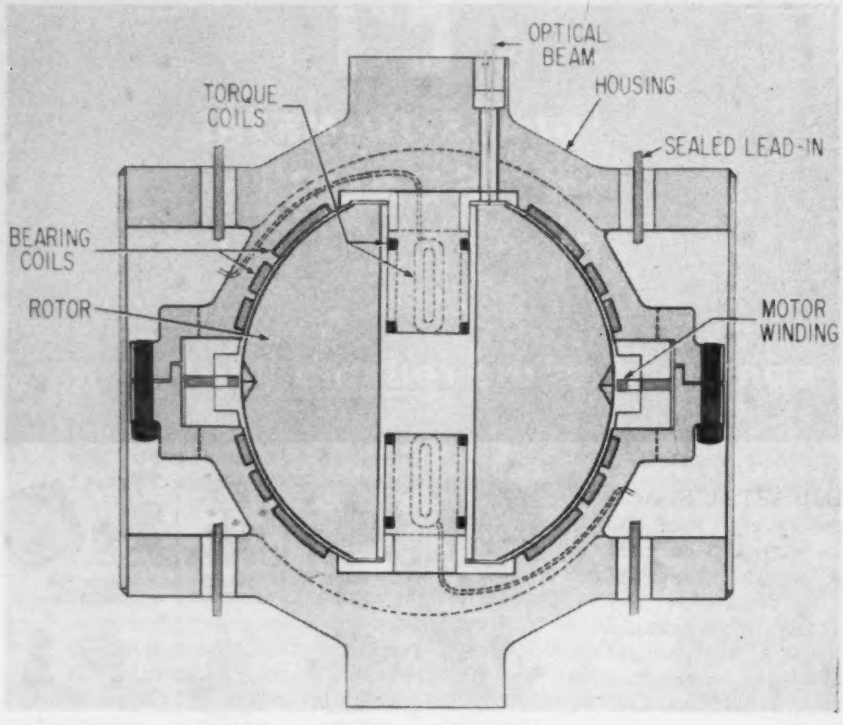

Fig. 1 Cutaway shows design features of cryogenic gyroscope under development by General Electric Company's General Engineering Laboratory. Promising accuracies many times greater than previously possible the gyro's rotor rotates at high speed inside a vacuum. Superconductivity induced by temperatures near aboslute zero makes it possible to suspend the rotor solely in a magnetic field.

Fig. 2 Once this golfball-size sphere is set in motion it may be able to spin freely for years. It is an important part of a new super-accurate gyroscope being developed at General Electric's General Engineering Laboratory. Engineer Karl F. Schoch holds the sphere which will rotate like a tiny earth, at high speed in a vacuum suspended solely by an invisible magnetic field.

TABLE I

Basic Cryogenic Phenomena

SUPERCONDUCTIVITY

At temperatures within a few degrees of absolute zero, about 20 metals—mercury, lead, tin, niobium, and tantalum to name a few—and many compounds and alloys have no electrical resistance. Currents in a superconductive circuit flow forever unless deliberately interrupted.

MAGNETIC FLUX TRAPPING

A current trapped in a superconductive coil creates a magnetic field which stays constant indefinitely. If the dimensions of the coil do not change, the current stays constant, too.

MAGNETIC "INSULATION"

Up to a certain strength a magnetic field cannot penetrate a superconductor. The field induces permanent counter currents on the surface of the superconductor, which repel the first field. The superconductor therefore acts as an "insulator" for magnetic lines of force.

CRITICAL FIELD STRENGTH

A superconductor will become resistive if placed in a magnetic field of a certain strength—the critical field strength. This value varies with different materials and at different temperatures in the cryogenic range.

HIGH FREQUENCY BEHAVIOR

Alternating currents in superconductors exhibit some resistance noticeable only at high frequencies (above 10 megacycles). But surface resistance and consequent losses in super-conductors are still far lower than those of even copper or silver at low temperatures. This behavior is explained by the hypothesis that superconductors have super-electrons that avoid collision with the crystal lattice as well as normal electrons which under a-c conditions can have collisions. (These collisions constitute electrical resistance.)

Possible Applications Of Cryogenic Phenomena

SHAPING OF MAGNETIC FIELDS

Since superconductors "insulated" or shield a magnetic field, it seems possible by proper flux shaping to construct magnetic lenses with reduced lens errors and therefore greater resolving power than ever before. An electron microscope with such a lens might permit atoms to be seen.

CURRENT STANDARDS

A superconductive coil with a "frozen-in" circulating current makes a very accurate standard of reference. Any current to be measured needs only to be conducted through the cryogenic environment and its magnetic field compared with that of the standard by available techniques.

FRICTIONLESS BEARINGS

With a proper coil arrangement and a "frozen-in" flux, a bearing can be made that will suspend a superconductor in space. High bearing stiffness can be obtained and mechanical wear eliminated. Such a bearing will work in a vacuum.

MOTORS

A cylindrical or spherical cryogenic body can be turned by a rotating flux produced by a polyphase winding. Such a motor would have an efficiency very close to 100% (ignoring losses in the power supply).

GYROSCOPES

Through the use of superconducting bearing and motor principles, gyroscopes with greatly improved accuracy are possible. Superconducting gyros used together with superconducting accelerometers and cryotron computers can lead to higher precision navigation systems in the future.

AMPLIFIERS

A superconductive d-c to a-c amplifier could be built having no zero drift and no noise. A signal source would feed a control current into a lossless superconductive control winding. The flux from this winding is chopped by a rotating superconductive disc consisting of segments which act as magnetic insulation. In a second winding an a-c voltage and output power are produced.

COMPUTER ELEMENTS

All basic types of computer circuits can be built from combinations of cryotrons—a relatively simple tiny device consisting of a thin film gate "wire" influenced by a control "wire" —both superconductive. Current in the control wire creates a magnetic field to destroy the superconductivity of the gate wire, making a two-position switch. Computers of small size and low power requirements are possible with cryotrons. The entire computer is encased in low-temperature surroundings.

OSCILLATORS

Resonant cavities with very little damping (Q numbers in the millions) are possible with superconductors because of their very small surface resistance at high frequencies. It seems possible that frequency standard oscillators using such cavities can be made with accuracies approaching those attained by atomic clocks. At low temperatures the mechanical stability of a resonant cavity is extremely high because metals don't creep, expand, or contract under these conditions.

POWER EQUIPMENT

At the present time, use of superconductivity in the power field is not economical because of the high cost of maintaining the very low temperatures required. But if materials can be found that become superconductive at the temperature of liquid hydrogen or still better, that of liquid nitrogen, the cost picture will change. It would then be practical to consider the use of superconductors for special transformers, generator stator windings, the coils of big particle accelerators, and large coils for energy storage and discharge systems.

BERNOULLI-DISK MAGNETIC MEMORY

Fluid Motion Principles Control Separation Between Disk and Heads

A novel memory device, particularly applicable to satellite and spacecraft applications, was revealed recently at the Eastern Joint Regional Computer Conference, Hotel Statler, Boston, Mass., by Robert Kelner, Manager of the Computer Products Div. of Laboratory for Electronics, Inc., of Boston, Mass. The new device overcomes previous limits to the density of data storage set by mechanical tolerances associated with the spacing between head and storage medium.

The new device, a working model of which was demonstrated at the conference, (see Fig. 1) is known as the LFE Bernoulli-Disk. It utilizes, in part, principles of fluid motion derived from the conservation of energy in liquids and gases first discovered in the early eighteenth century by Swiss Scientist, Daniel Bernoulli. Principles of fluid motion are used to maintain a controllable and small separation between the storage medium and the read-write heads of the memory unit.

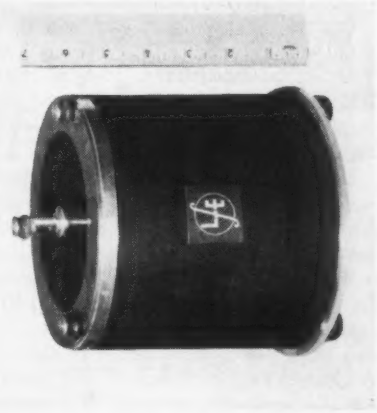

Fig. 1 New Magnetic Disk Memory System, developed by Laboratory For Electronics, Inc., to meet extreme environmental conditions encountered by missiles and space satellites.

The Bernoulli-Disk consists of a flexible mylar magnetic disk that is rotated close to a smooth stabilizing backplate in which read-write heads are imbedded flush with the smooth surface. The tape disk is attached by flanges directly to the shaft of an electric motor, and an air-inlet orifice is located at the center of the backplate so as to permit air to enter between the rotating disk and the stabilizing plate.

When the tape disk is at rest, it falls away from the backplate; but in motion, the limp disk becomes flattened

by centrifugal force and the disk pumps air through the orifice and out at the disk periphery. At this point the hydrodynamic forces of the air between the disk and the stabilizing plate together with the dynamic and elastic forces of the revolving disk, cause the disk to conform to the backplate at a controllable and small separation.

The development of the Bernoulli-Disk, Kelner said, is the result of the fundamental problem of reliable head to medium separation, and provides the computer industry with a replacement for the conventional, universally-used, high-speed, medium-capacity magnetic drum. Objectives of this program included: elimination of costly and treacherous close-tolerance head-mounting; reliably reducing head-medium separation for shorter wavelength recording; substantial increase in compactness and decrease in weight; and the withstanding of stringent environmental conditions. It was stated that the new device, has demonstrated in actual tests that it meets all these objectives.

Turning to the advantages offered by the Bernoulli-Disk over the conventional magnet drum, Kelner cited the following:

- Reliability—Due to the low mass of the revolving disk and the positive separation maintained between disk and back plate, possibilities of damage to the read-write heads of the recording medium are virtually eliminated;
- Shock-Resistance—The low mass of the recording disk provides a device that will stand extreme shock;
- Low-Power—The device can be constructed to operate with extremely low power requirements and could be operated off Solar Cells;
- Size and Weight—The size and weight of the Bernoulli-Disk is only a fraction of that of a conventional drum;
- High-Speed—Due to the low mass of the revolving disk and the close control of separation, it is possible to operate the new device at speeds greater than the 10,000 rpm maximum of the conventional drum;
- Temperature—The device will operate over a wide temperature range, and is designed to meet advanced military temperature specifications, including rapid change of temperature;
- Low-Cost—A most important advantage of the Bernoulli-Disk is its simplicity and extremely low cost—achieved through elimination of need for complex machining.

These advantages, have been demonstrated by actual laboratory tests, Kelner said. A recorded track of sinusoids at several hundred wavelengths per inch, for example, showed no serious amplitude modulation, even when the apparatus was pounded violently on a bench. Other laboratory experiments have indicated excellent stability including tape dimensional ability in test models operating in excess of 1000 hours continuous duty. Stop-start cycling experiments have demonstrated no appreciable wear to heads or tape after 3,000 cycles.

The potential universality of the Bernoulli-Disk, Kelner stated, now appears to exceed even the initial expectations of the scientists responsible for its development. Staff members of the Storage Device Group of the Computer Products Division now are exploring application of the device to a wide variety of information storage problems covering the whole field of ground and airborne digital computers —particularly equipments designed for missiles, spacecraft and satellites, where the Bernoulli-Disk is the simplest rotating memory device that can meet the shock and environmental conditions there encountered.

The Bernoulli-Disk, he said, is a proprietary development for which patents have been applied. This development has now reached a stage where Laboratory for Electronics is prepared to develop disks for customized application.

Circle No: 108 on Inquiry Card

LINEAR POSITIONING MOTOR

Simple Inputs Translated Into Accurate Linear Motion

A new control device, called the Linear Positioning Motor, responds to an input with a rapid linear movement of its shaft to any of several accurate positions. Exact amount of shaft movement is determined and selected by simple input devices such as switches, relays, push-buttons, contacts, etc., or by more complex digital inputs.

As the input is selected, the shaft of the motor moves to the corresponding position in forceful motion, uninterrupted by intermediate reference points, stops, ratchets, etc. Repeatability within 0.005 inch, travel times of 100 milliseconds, and thrusts of 100 pounds or more are possible. Laboratory models have been constructed with a repeatability of many times this value, but these are not yet commercially available. The shaft of the motor is the only moving part . . . there are no gears. It moves in a linear direction only, although the shaft is free to rotate with the attached load, if necessary.

The shaft of the motor can be attached to either a load that requires only simple positioning, such as a slide switch, or to a load that requires a linear positioning superimposed on an existing rotary motion, such as the faceplate of a clutch or the spindle of a drill press. A variety of couplings and internal bearings can be used for specific applications. Fig. 1 shows some general applications.

The motor responds to an input by an immediate acceleration of the shaft and load, followed by a deceleration

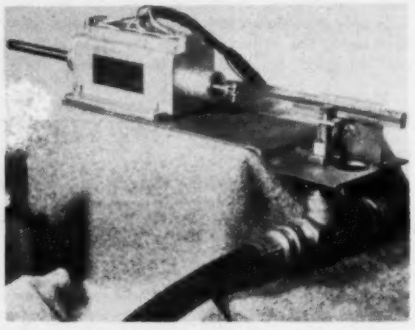

Fig. 2 Model B1002 Linear Positioning Motor coupled to a gear on the stem of a gate valve. The input device for this model can be any type of switch or relay. Input cable entering motor at top connects to input taps. In this application, the motor is controlled to rotate the valve stem, positioning the valve in any of 27 positions. As many as 100 positions could be controlled.

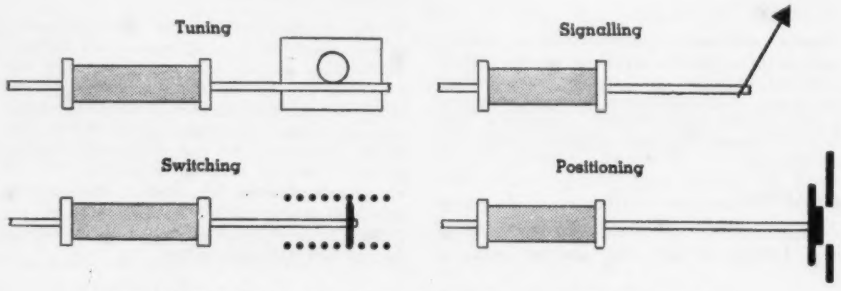

Fig. 1 General applications of the Linear Positioning Motor.

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You can depend on high performance and dependability at all times with the complete line of control synchros (transformer differential and transmitter), produced by the Instrument Division of American Electronics, Inc. Used as a family or independently in system applications, these units will operate over a temperature range of −55° to +125°C... and can be supplied to operate up to 200°C.

Available in frame sizes from 8 to 25 these synchros meet and exceed the stringent standards of MIL-SPEC. 20708.

The key to proven reliability lies in the quality features engineered and manufactured into each unit. Greater stability and corrosion resistance is accomplished by stainless steel housings. Encapsulated unit construction and hermetically sealed windings are used to withstand the extremes of vibration and shock. Through-bore construction means fewer parts and less space in which damaging moisture may collect.

SIZE 11 ELECTRICAL DATA

	11E22M-81G (Transformer)	11E22M-01F (Transmitter)	11E22-81J (Differential)
PRIMARY	Stator	Rotor	Stator
INPUT (VOLTS)	11.8	115	11.8
TEST (VOLTS)	10.2	115	10.2
FREQUENCY (CPS)	400	400	400
Z_{RO} ROTOR IMPEDANCE (STATOR OPEN CIRCUITED) (OHMS)	3340 /79°	2000 /80°	107 /78°
Z_{SO} STATOR IMPEDANCE (ROTOR OPEN CIRCUITED) (OHMS)	570 /80°	18 /79.5°	92 /80°
MAX. NULL VOLTAGE (FUNDAMENTAL) (VOLTS) (TOTAL) (VOLTS)	.030 .040	.015 .020	.015 .020
MAXIMUM ERROR (MINUTES)	3	3	3
TRANSFORMATION RATIO (R/S) ±4%	2.203	.103	1.154
PHASE SHIFT (DEGREES)	5	6	6
D. C. RESISTANCE (OHMS) STATOR ROTOR	60 385	3 185	11 19.0

FOR INFORMATION ON SIZE 8 AND OTHER SIZES WRITE FOR SPECIFICATIONS.

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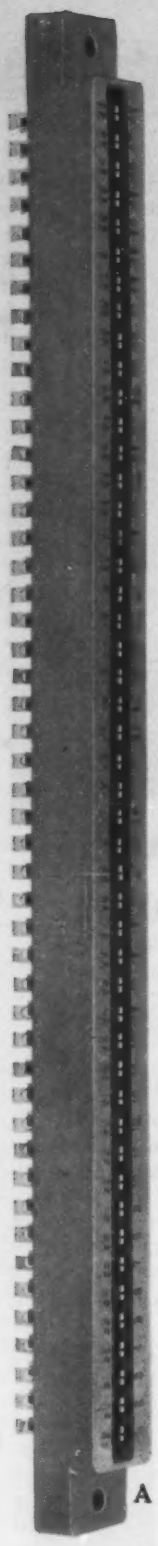
CIRCLE NO. 22 ON INQUIRY CARD

Continental Connector Announces

NEW PRINTED CIRCUIT CONNECTORS

4 New Designs for Computer Applications



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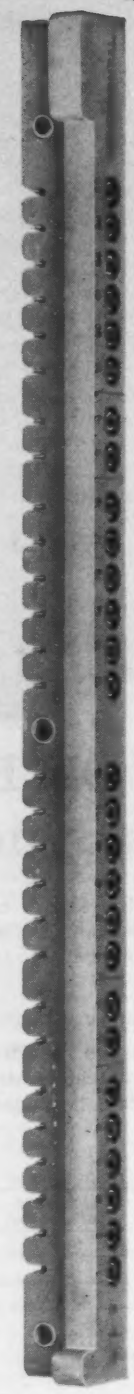

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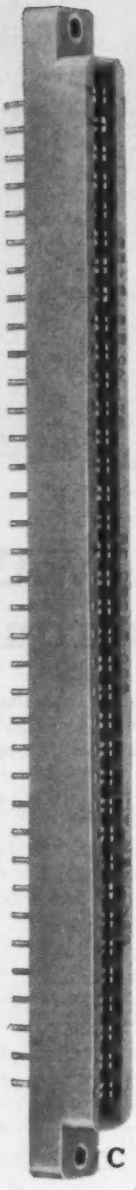

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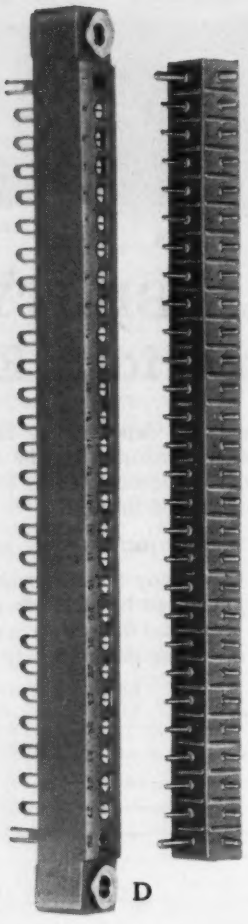

D

A—48-contact printed circuit connector for 1/16-inch printed circuit board; dual row, up to 96 connections. "Bellowform" contacts.

B—Test Point Connector. 28 closed entry contacts, threaded mounting inserts molded into body. For dip soldering to printed circuit board.

C—36-contact printed circuit connector for 1/16-inch printed circuit board, featuring new "Bellowform" contacts.

D—Right angle plug and socket for dip soldering to printed circuit board; floating mounting bushings, 28 contacts.

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Proven reliability . . . high precision . . . choice of molding compounds. Write for details on complete line of printed circuit connectors to Electronics Division, DeJUR-AMSCO CORPORATION, 45-01 Northern Boulevard, Long Island City 1, N. Y. (Exclusive Sales Agents).

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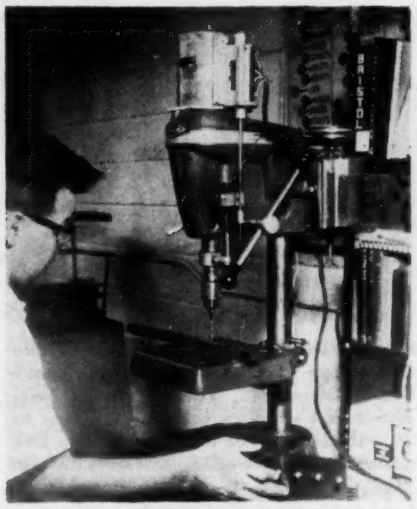


Fig. 3 Two Linear Positioning Motors are used in this application. One unit mounted vertically sets depth limits. The other more powerful unit mounted on top of the drill press performs the pressing. The operator is selecting one of the control positions.

as the shaft approaches the control point (selected position) where it stops. Action of the motor can be compared to that of a piston, controlled by an elaborate servo system; however, the motor does not require external error detection or amplification, since these are inherent. By proper programming and other techniques, overshoot of the shaft can be held to a minimum, or even eliminated, depending upon specific requirements.

Characteristics of the motor are different from those of a solenoid or air cylinder. While the solenoid and air cylinder are essentially two position devices, the positioning motor may be constructed with many possible positions. Present design makes it possible to have an unlimited number of positions with a resolution of 0.010 inch.

Both coarse and fine positioning are possible. Coarse positioning is determined by input taps. Fine positioning is accomplished by setting a potentiometer or decade resistance box.

Figs. 2 and 3 illustrate applications of this novel component.

Linear Positioning Motors can be designed with thrusts from a few ounces to several hundred pounds, with any number of positions, with coarse and/or fine adjustment, and with stroke lengths from a fraction of an inch to several inches.

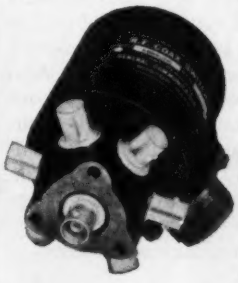
Patents for these motors have been applied for by Tronics Corp., Minn., Minn.

Circle No. 105 on Inquiry Card

An Important Message...

To The Engineer Specifying

COAXIAL SWITCHES



GCC is the oldest manufacturer of coaxial switches. In fact, we were the originators of designs now so widely imitated.

GCC offers the most complete . . . the most versatile line of coaxial switches covering the widest field of applications.

GCC continues to keep up its lead in the field of coaxial switches. The miniature coaxial switch series is just one example.

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Low VSWR *Long life*
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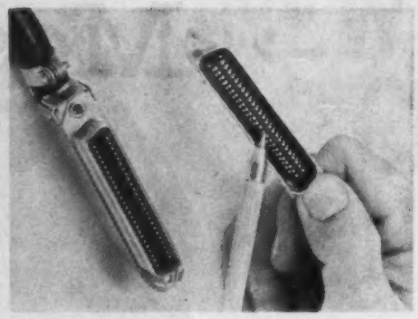

Fig. 1 Body of the connector (indicated by pencil), molded of diallyl phthalate compound, firmly holds fifty gold-plated cadmium bronze contacts. Male member of the connector (held in hand) is protected by a metal guard. Both sets of terminals flex—insuring continued contact during vibration and shock. Diallyl phthalate exhibits good molding detail and excellent insulating properties even in moist atmospheres.

Fig. 2 Illustrative applications of the connectors are in the Bell System's "Call Director". This versatile telephone can pick up calls on as many as 29 outside lines or extensions, or a like number of inter-office lines. With the "Call Director" it is also possible to hold calls, conduct conference calls with as many as six people at one time, and to reach frequently called people by dial or push button signalling. Connector facilitates rapid installation and maintenance.

ELECTRICAL CONNECTOR

More Contacts In Smaller Space With Improved Molding Resins

Fifty gold-plated, cadmium bronze contacts held firmly in a body molded from an improved type of diallyl phthalate resin are the key to a small electrical connector manufactured by Amphenol-Borg Electronics Corp. About the size of a cigarette lighter, the connector is particularly applicable to business machines and multi-line telephone installations, where many low voltage circuits must be connected and disconnected with a minimum of complications.

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Basic to the design of the intricate connector is an insulating base material that maintains excellent di-electric values under high humidity and temperature conditions. Amphenol chose a molding compound based on the Dapon diallyl phthalate resins supplied by Food Machinery and Chemical Corp. Dapon resins combine excellent low-moisture absorption with insulating properties. Pieces molded from Dapon maintain high-impact strengths and dimensional stability in high humidity atmospheres according to the Food Machinery & Chemical Corp.

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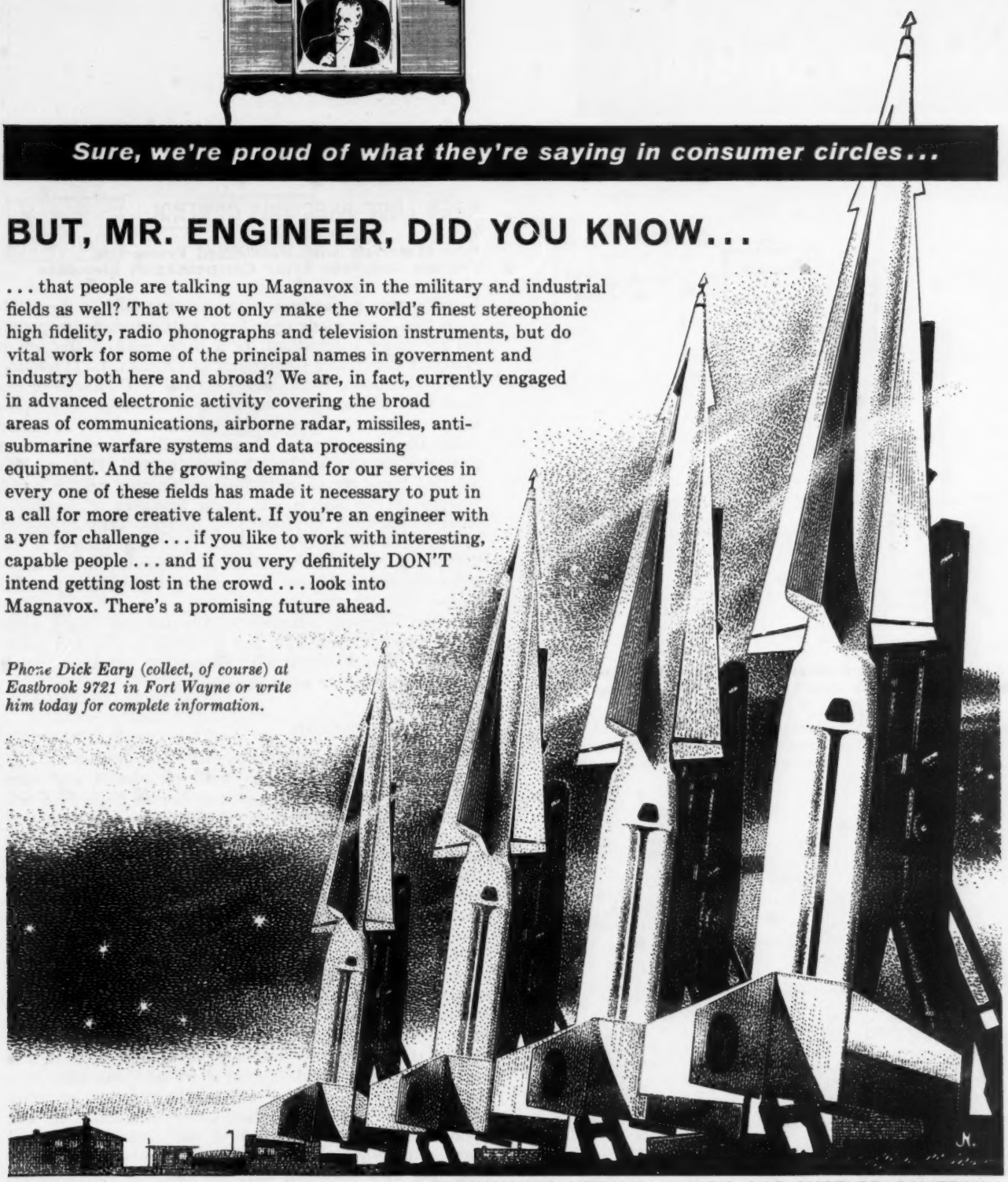

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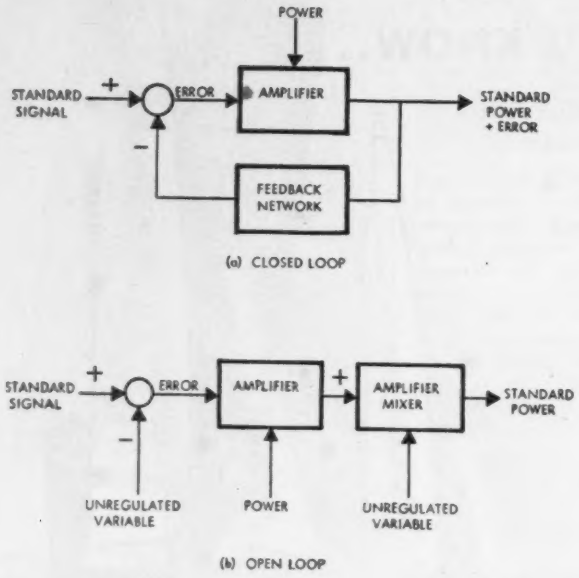

Fig. 1 Basic block diagram of comparative closed and open loop systems. (a)Closed loop (b)Open loop.

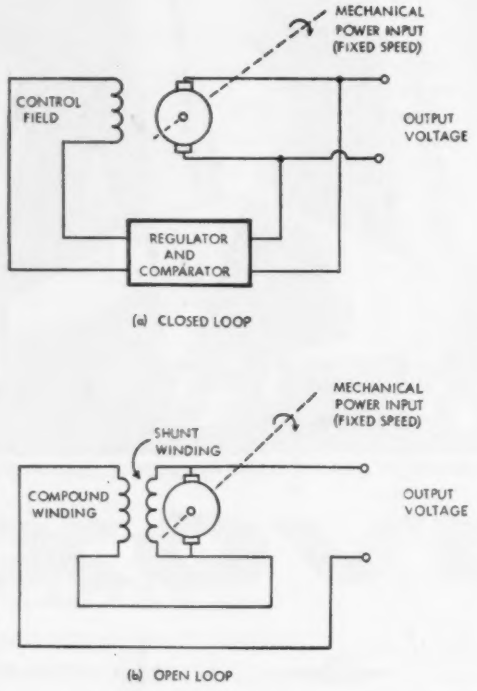

Fig. 2 Schematic diagrams of comparative closed and open loop direct current generator with voltage control. (a)Closed loop (b)Open loop.

OPEN LOOP PRECISION CONTROL

New Materials with Prescribed Properties Provide Accurate Error Compensation Elements

Development in the basic sciences, especially in the solid-state field, have made open-loop control techniques practical for many applications. In a paper read at the recent National Electronics Conference in Chicago, L. J. Johnson of the Hallamore Electronics Co., and S. E. Rauch of the University of California and Ramo-Wooldridge Corp., presented arguments and examples showing how, in many cases, direct application of a physical phenomenon as a standard can produce very accurate control. They pointed out that these open-loop techniques simplify synthesis and analysis of the system and avoid problems of instability often encountered in closed-loop designs. They suggested that systems designers re-evaluate open-loop control in the light of the precise compensation obtainable by made-to-order devices produced by molecular engineering techniques.

In the following discussions, Johnson and Rauch compared direct compensation and feedback control and pointed out some applications where open-loop techniques using precise elements are most appropriate.

GENERAL COMPARISON

Consider the block diagrams of Fig. 1, illustrating the fundamental difference between feedback control and open loop, direct compensation control. In the basic feedback control loop a reference, employing some physical phenomenon as a standard, is used as the desired level of the output, and actual output is fed back and compared with this standard reference. Difference between the standard and the output activates a correction in the excitation function, which reduces the error between the output and the standard. Thus, the closed loop, feedback compares the output of an element or group of elements to a reference signal to provide an actuating signal for controlling the output.

Figure 1b is a corresponding block diagram of an open loop, direct compensation control. Again, a standard is employed, but in this case it is compared with an unregulated phenomenon. The error for any operating condition is pre-determined. A compensating element or group of elements is added to produce a compensation equal and opposite to the natural error of the element. In actual practice, it frequently is desirable to employ a low power level unit as a standard; than the mode of compensation must be at a level of power considerably less than that at the output terminals. Note that for the direct compensation technique the output of the loop is not compared directly with any signal to provide the net input to the loop.

Figures 2 and 3 illustrate specific comparative examples of the two types of control. Figure 2a shows a simplified schematic diagram of a direct current generator in which the output voltage is controlled by means of a feedback voltage regulator. Fig. 2b is the corresponding circuit diagram of a d-c generator in which the output voltage is maintained nearly constant by using a compound winding. The compound winding produces a correcting excitation

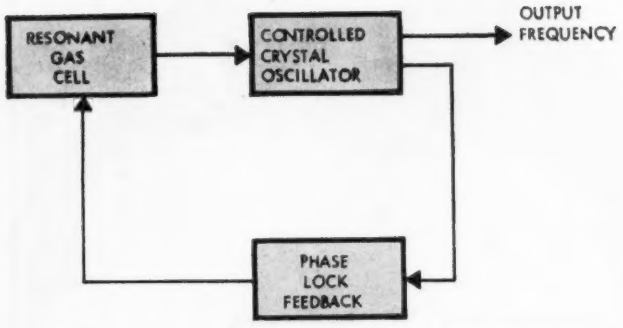

Fig. 4 Open loop atomic clock absolute frequency reference, closed loop phase lock control.

field which compensates for the voltage drop in the generator resulting from the load currents in the generator. Proper choice of the number of turns in the compound winding can be pre-determined by knowing the generator characteristics; thus, direct compensation can be achieved. It may be argued that the passage of load current through the compound winding is a feedback function; however, no comparison with a reference signal has been made to activate a correction signal. No path exists in which the error operates to reduce itself.

An example from static systems is the standard temperature control shown in Fig. 3. An oven temperature in Fig. 3a is regulated by standard feedback amplifier techniques. The thermistor bridge circuit provides a signal to an amplifier which regulates the heat produced in the oven. The system operates to maintain a balanced condition in the thermistor bridge, which in turn controls the oven temperature. In the open loop oven control of Fig. 3b the thermistor acts as a series-controlling non-linear resistor. When the temperature of the thermistor reaches a critical value, a rapid change of resistance occurs which decreases the power demand.

A very recent example of an open loop frequency control with an added closed loop phase lock is to be found in the gas cell clock of Fig. 4. A frequency resonant lamp activates a gas cell, such as Rb^{87} or NH_3, and its beam modulates a photocell. The gas cell is irradiated with microwave power from a waveguide horn. Change in the optical properties of the gas is detected by the photocell. The oscillator is locked to the atomic resonance of the gas cell by the signal output of the phase detector fed through a servo frequency control element for a crystal oscillator. A low frequency modulation is employed to obtain the phase lock.

FREQUENCY CONTROL

For a more detailed comparison of closed and open loop control, Johnson and Rauch described the performance characteristics of a feedback and a direct compensated frequency control system.

The design objectives were to obtain a steady state accuracy of 0.1% in both cases. Actual results obtained steady state accuracies better than 0.1%. The important point to note is that the feedback control approach showed extreme inflexibility to an order of magnitude improvement, while the direct compensation approach could be improved with

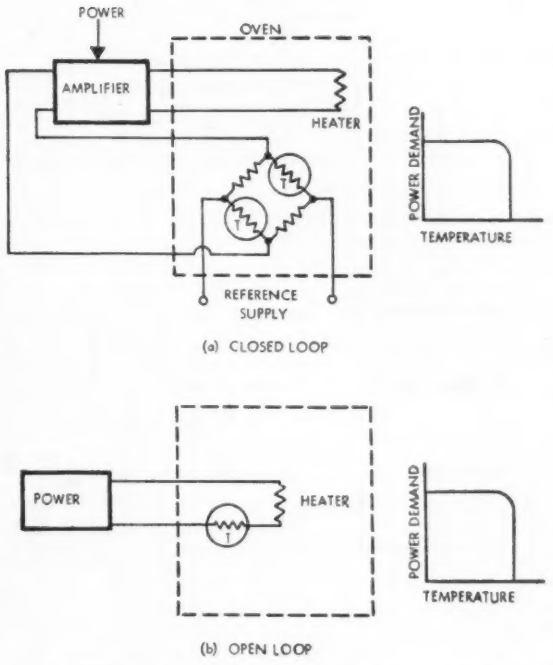

Fig. 3 Comparative circuit schematics for c'osed and open loop temperature control. (a)Standard feedback amplifier techniques (b)Open loop oven control.

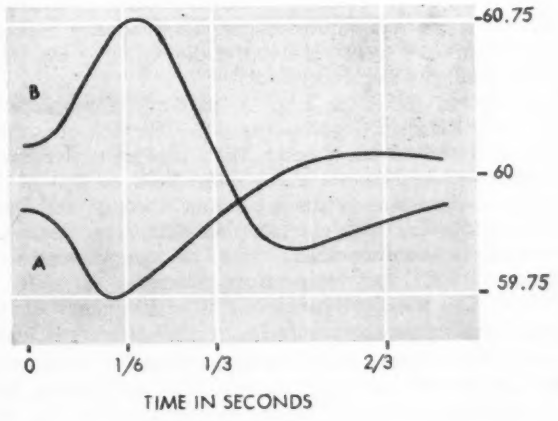

Fig. 6 Oscillogram of frequency transient.

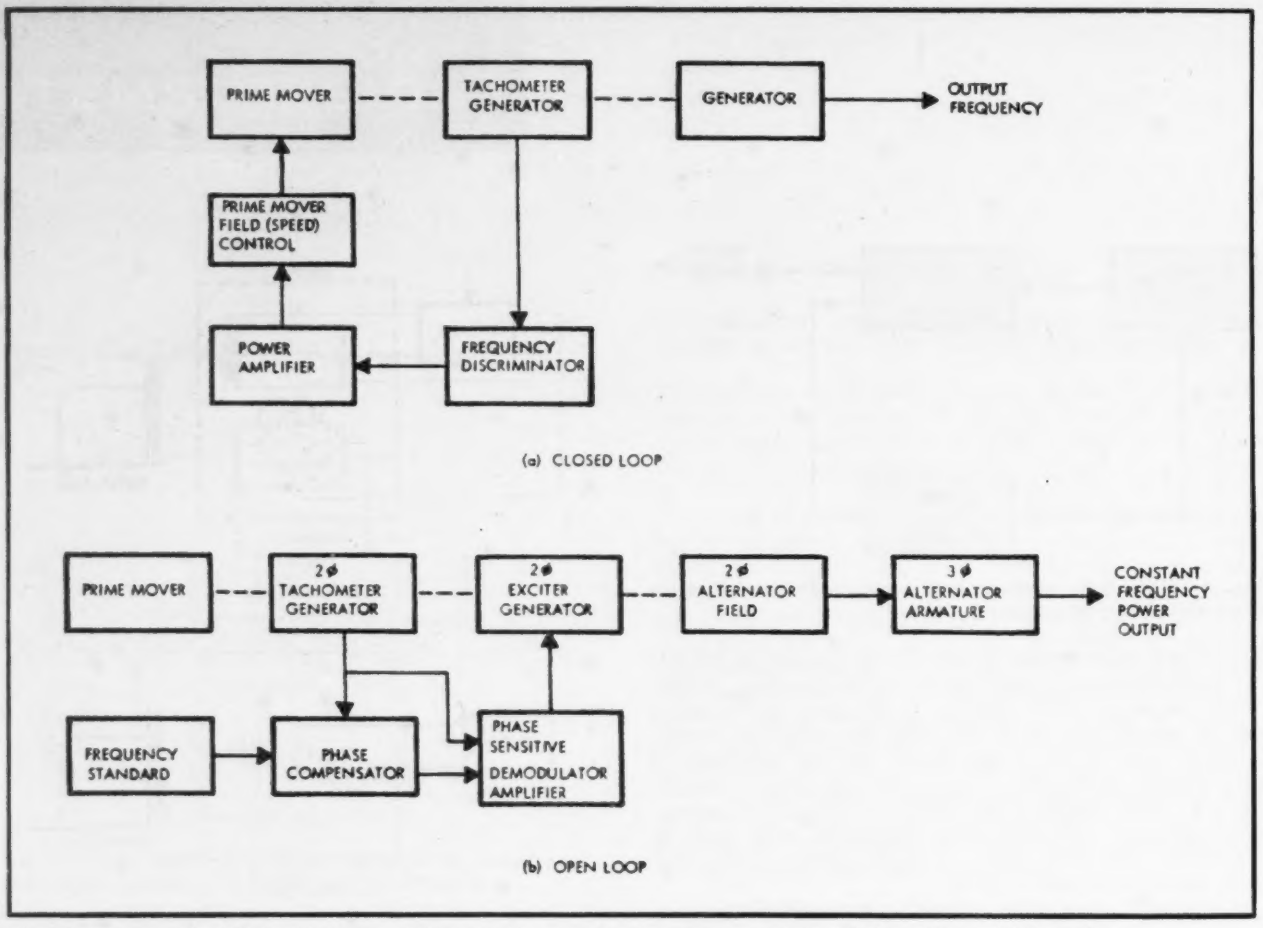

Fig. 5 Comparative block diagrams of closed and open loop frequency control. (a) Closed loop (b) Open loop.

a simple change of standard to obtain accuracies of several orders of magnitude improvement. In the latter case the higher accuracies were achieved without facing the problems of feedback instabilities.

The system shown in Fig. 5a employs a proportional error control without error integration. The unit consists of a speed control dynamometer with the controller maintaining a constant speed though the field control of the driving motor. Speed errors are sensed through stabilized, tuned circuits and high-gain amplification. The device, as developed, maintains steady state frequency control to within ±0.05% for temperature changes of +40 to +140°F. The transient behavior of the frequency control system holds frequency accuracies to ±1% deviation, which is one order-of-magnitude error larger than the steady state case. The system has approximately critical damping, having a response characteristic as presented in Fig. 6a. Stability of performance was obtained through use of additional damping circuits in the controller. Transient behavior of the system becomes increasingly critical in design requirements as the steady state accuracies are improved. In other words, the developmental effort required to improve the steady state accuracies by an order of magnitude is prohibitive in time and cost. If the long term steady state errors were reduced an order of magnitude by integration, no proportionate transient improvement would occur; therefore, the overall transient frequency stability would remain at the approximate one percent level.

In the open loop direct-compensated frequency control system of Fig. 5b, the method of control is independent of the drive speed. Compensation, open loop in nature, employs the tachometer generator for speed sensing. The tachometer generator signal is compared with a frequency standard through phase sensitive demodulator amplifiers. Resulting signals from the phase sensitive demodulators are sent through another stage of amplification as a direct frequency make-up which inherently compensates for mechanical rotation deficiencies of the prime mover. In other words, an electrical rotation obtained by phase comparison methods is added to the unregulated mechanical rotation, thereby producing an absolute frequency control by compensation methods. Electrical rotation as applied through field windings in the special machine configuration requires additional phase compensation to provide continuous frequency stability throughout transient speed changes. The required compensation can be predicted to extremely high degrees of accuracy and can be compensated with a simple linear network. Johnson and Rauch said it can be shown that the frequency stability is predominantly that of the frequency standard, which is 0.1%. A distinct advantage in frequency control and flexibility is inherent in this direct compensation approach, they said, since improvement in absolute accuracy and transient stability can be obtained by a simple substitution of improved frequency standard sources. Thus, for example, a thermally controlled crystal oscillator can be substituted for a tuning fork oscillator, thereby changing the absolute accuracy from 0.1% to 0.001% with no other change in the system.

End

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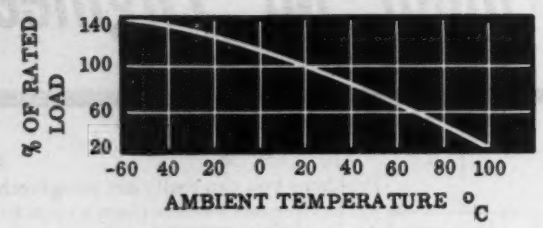

Fig. 2 Derating curve

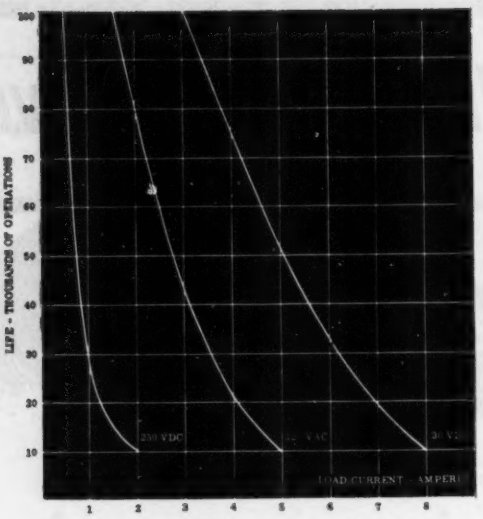

Fig. 1 Contact life vs. contact current

CURRENT CARRYING CAPACITY OF SWITCH AND RELAY CONTACTS

by Austin Whys

Bendix Products Div.—Missiles, Bendix Aviation Corp., Mishawaka, Ind.

This digest of information was gathered from many sources over the past 5 years and prepared for the Bendix Talos Parts and Materials Handbook to guide systems designers in applications of switches and relays.

Standardization of contact ratings is very difficult because of numerous interacting factors. The amount of current a set of contacts can make, break, and continuously conduct is affected by:

- Value of open circuit voltage;
- Type of power, i.e., d-c, sine wave, square wave, frequency;
- Type of circuit being opened and closed, i.e., resistive, inductive, lamp, motor;
- Expected life, number of operations and duty cycle;
- Contact material, configuration and size;
- Opening and closing force;
- Speed and amount of separation;
- Temperature, pressure and type of fluid surrounding contacts.

MAKE

As the contacts come together, there may be a discharge across the gap or through a resistive surface film. If the contacts bounce this discharge is repeated several times and each time may cause splashing of molten contact metal which may weld the contacts together. The current must be kept below the value that would cause sufficient welding to resist the separating force applied to the contacts.

BREAK

The current must be kept below the value that will maintain an arc when the contacts are completely separated. For a given relay design this current value will depend upon the value of open circuit voltage, its wave shape, and the type of circuit the current is flowing through, i.e., resistive, inductive, capacitive.

CONTINUOUSLY CONDUCT

Contacts can continuously conduct many times the amount of current they can make or break. The only limitation to the amount is the heating effect due to contact resistance. This characteristic is seldom useful but when it can be applied, the savings of space and cost are considerable. In one application of a reversing switch for a d-c arc welder, the switch was operated only when the welder was off, thereby allowing the use of a 15 ampere rated switch even though the current through the contacts was 70 amperes.

REPETITIVE MAKE AND BREAK

Contact rating for many thousands of operations is lower than that obtained by considering only arc maintenance and contact welding. Each operation will be accompanied by some arcing and/or metal transfer, and/or mechanical wear and/or increase in resistance which will eventually make the contacts unusable for a given application. Figure 1 is a typical rating curve for contacts on one type of relay from one manufacturer. The same principle applies to any other contacts, but shape of the curves and the values will be different depending on materials, configurations and dimensions of contacts.

PARALLEL CONNECTIONS

Connecting pairs of contacts in parallel may be useful in dry circuit applications because it will increase the probability of making the circuit on each operation; however, it will not increase the current rating because the contacts will not make and break simultaneously.

EFFECT OF LOAD CIRCUITS ON CONTACT RATING

For some loads the inrush current is considerably higher than the nominal current, examples being lamp or tube filaments, relay and solenoid coils, motors, and capacitors. A filament load will draw 5-10 times nominal because a filament's resistance is much lower when it is cold. A motor load will draw 5-10 times the normal running current because back emf doesn't build up until the motor is rotating. Relay and solenoid loads will draw many times nominal when operated on a-c power because the impedance is smallest when the movable core or plunger is in the unoperated position. For some solenoids the inrush may be as high as 10 times the holding current. A capacitive load will draw a high inrush current because a capacitor has zero impedance until it has acquired some charge.

Inductive loads increase arcing when contacts are opened because of the energy stored in the magnetic field which upon collapse generates a surge voltage whose peak value is many times the source voltage.

Table I is an example of the recommended ratings under various conditions for one type of switch contact. Values shown for multiple switches are amperes per pole except for motor load. Figures in the Table are maximum current ratings for 10,000 operations.

TABLE I
Ratings for Type X Switch

RATING	VOLTAGE VOLTS	CURRENT (amps)
Current capacity		
	15 DC	10
Lamp load hot	30 DC	7
filament current	130 AC	4
	15 DC	50
Resistance load	30 DC	25
	130 AC	15
	15 DC	25
Inductive load	30 DC	15
	130 AC	11
Motor load normal	15 DC	40
running (full load)	30 DC	20
current	130 AC	6
Current-carrying capacity (any voltage)		
Continuous		55
15 min. of each hour		60
5 min. of each ½ hour		90
1 min. of each ¼ hour		110
5 sec. of each ½ hour		250
Current making capacity		
Maximum in-rush	15 DC	100
on any type	30 DC	70
of load	130 AC	40
Emergency current-breaking capacity		
Opening circuit		
under emergency	15 DC	225
condition for 50	30 DC	100
operations only	130 AC	20

Longer life (more operations) can be expected when the switch is operated at less than maximum rating. These ratings are for an ambient temperature of 25° C. For other ambients derate as per Figure 2.

ARC SUPPRESSION

The arc obtained upon opening of contacts, in addition to damaging the contacts, may also cause:

- High voltage transients which may puncture insulation or damage other components in the circuit such as tantalum capacitors, diodes and transistors;
- RF generation which may interfere with adjacent circuits.

Because of these effects it may be desirable to reduce the intensity of the arc in some circuits, which can be accomplished by various methods, generally called arc suppression. Any method used will cause a delay in de-energization of the load which should be checked if timing is critical.

ARC SUPPRESSION FOR NON-INDUCTIVE CIRCUIT SWITCHING

A capacitor across the contacts will bypass current to limit arcing during contact opening until the contacts are adequately separated. When the contacts are closed they short the charged ca-

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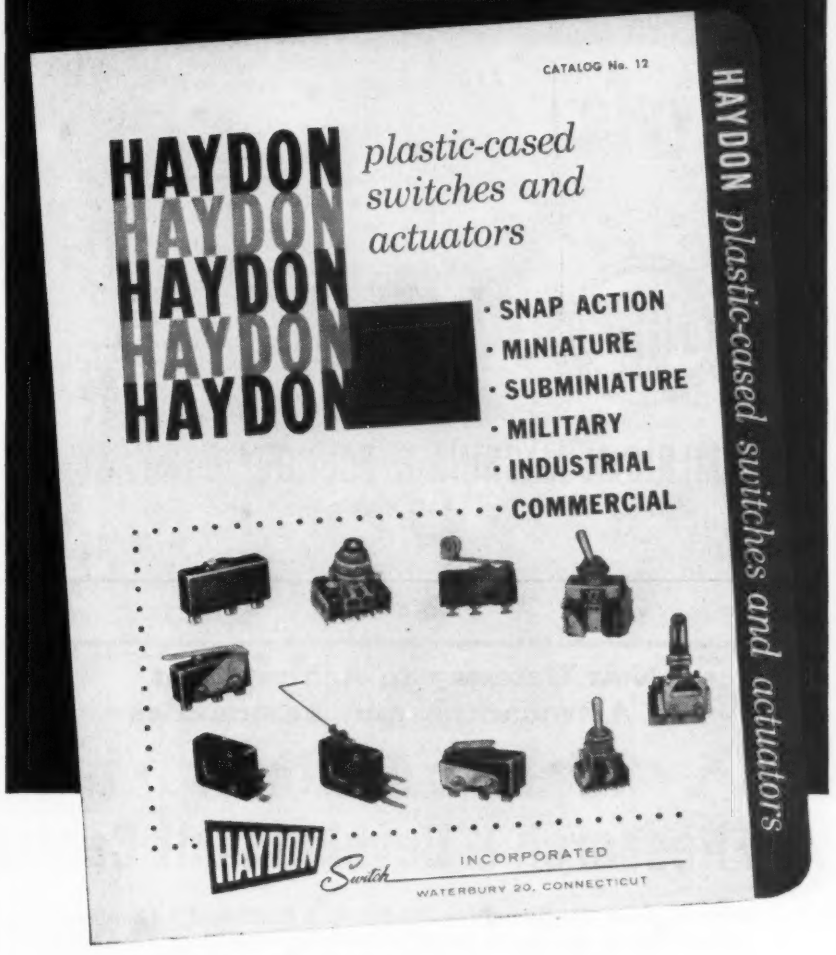

Catalog No. 12 describes a number of basic snap-action switches and switch-actuator assemblies. Types of switches available are:

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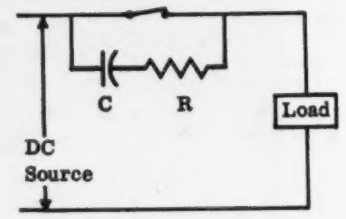

Fig. 3

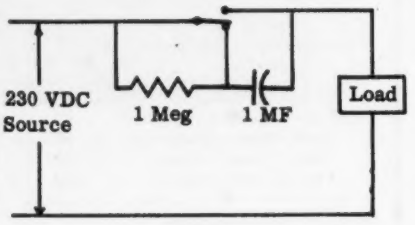

Fig. 4

pacitor resulting in a high discharge current through the contacts unless limited by a series resistance. The series resistor will reduce the arc suppressing effect of the capacitor and therefore its value should be no larger than necessary. On d-c heater loads up to 60 watts at 115 and 230 volts, contact protection is not required. The circuit and values of capacitors and resistors to be used above that loading are shown in Figure 3 and Table II. Use of this circuit not only reduces the arc but minimizes the transfer of contact material, which is a problem in d-c circuits. On loads above 7 amperes at 230 volts, the circuit shown in Figure 4 is effective and has the advantage of being noncritical as to the value of resistance and capacitance.

ARC SUPPRESSION FOR CONTACTS IN INDUCTIVE CIRCUITS

Opening an inductive circuit stores energy in the magnetic field when the

TABLE II
Protection for D-C Heater and Incandescent Lamp Load

LOAD IN WATTS	115 Volts DC C (mf)	115 Volts DC R (ohms)	230 Volts DC C (mf)	230 Volts DC R (ohms)
0 to 60	0	0	0	0
61 to 160	¼	0	¼	2
161 to 230	½	½	¼	2
231 to 500	1	¾	½	1
501 to 750	2	1	1	1
751 to 1000	3	½	2	2

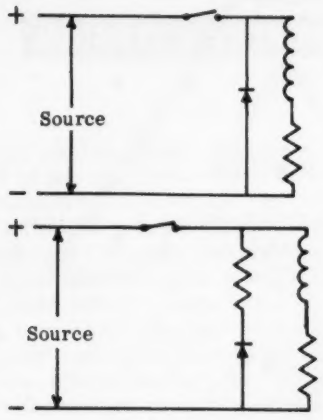

Fig. 5

source power is d-c or when the source is a-c and the interruption occurs at other than the zero power portion of the cycle. This stored energy has to be dissipated and if no easier path is available, it dissipates in an arc across the contacts. One method of reducing the contact arc is to provide another path to dissipate the energy. Since there is no means for accurate calculation of the performance of such circuits, the usual procedure is to try various combinations of capacitors and resistors connected in the circuit shown in Figure 3, and observe the arc visibly or by oscilloscope. Experience develops ability to judge when the best combinations has been found, but sometimes other tests are necessary to supplement that judgment.

Another method of reducing contact arcing in d-c inductive circuits is to insert a diode in parallel with the load polarized to present high impedance to the source voltage. (See Figure 5.) When the circuit is interrupted, the polarity of the induced power will be such that the power flows easily through the diode and is dissipated in the load resistance. If the resistance in the load is insufficient, a resistor may be added in series with the diode.

The reverse resistance characteristic of selenium and germanium diodes makes possible still another method of reducing arcing. Excellent application information for this purpose can be obtained from manufacturers of selenium and germanium diodes. Since both selenium and germanium can not be operated at high ambient temperatures, they are not recommended for missile application.

SWITCHING LOW VOLTAGE CIRCUITS

When the voltage across closed contacts is increased from zero, the current through the contacts does not always increase in direct proportion to the voltage because the contact resistance sometimes decreases in steps. An insulating film of some kind prevents ini-

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tial electrical closure and the contact resistance due to this film can be in the order of hundreds of thousands of ohms. When dielectric breakdown occurs between contacts, the film is burned away at one or more points and the contacts move toward each other to establish metallic contact. A number of these small areas must be formed in order to produce enough metallic conducting cross-section to result in the contact resistance being lowered to a range of milliohms. If sufficient current flows through the first few areas, the contact resistance is quickly reduced to a few milliohms by actual melting and welding of several areas of contact.

As an example, consider a pair of contacts for which the dielectric strength and the thickness of film makes it necessary to have approximately 100 millivolts to cause breakdown. To conclude that proper contact operation will occur if there is 100 millivolts or more available across open contacts is incorrect as shown in the d-c amplifier circuit of Figure 6.

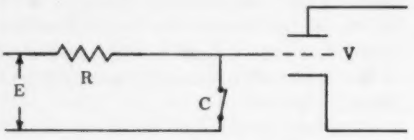

Fig. 6

The grid circuit of V has a bias supply, E, and a current limiting resistor R; C is a pair of contacts operated as part of a relay. When C is open, the full voltage of E will appear on the grid of V. When C is closed, it is desired that no more than 5 millivolts appear on the grid of V. Assume that E = 1 volt, R = 50,000 ohms, and that the film resistance of the closed contacts is 500 ohms. Under these conditions, the voltage across the closed contacts is 10 millivolts which may be insufficient to break down the film and so the 10 millivolts will remain on the grid causing circuit malfunction. Even though the open circuit voltage across contacts is one volt, only 10 millivolts appear across the contacts because of the "series resistance" of R.

DRY CIRCUIT SWITCHING

A dry circuit does not have sufficient power to cause softening, melting, arc transfer, etc. Only mechanical forces (wipe, impact, pressure) can affect the contact interfaces.

For low power switching, it is advisable to use switches and relays designed for dry circuit operation.

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TECHNIQUES IN THE APPLICATION OF SILICON POWER RECTIFIERS

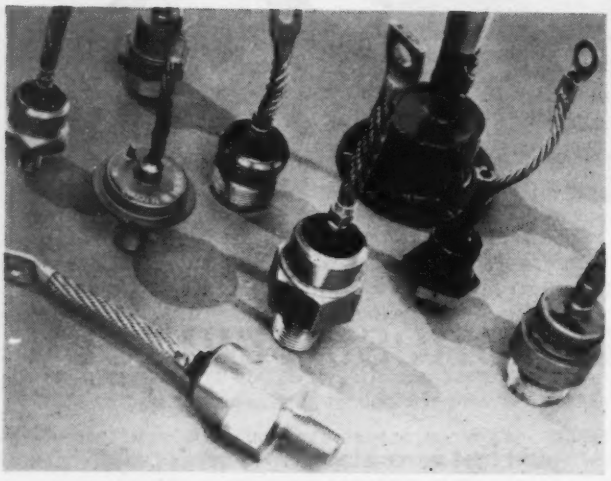

Fig. 1

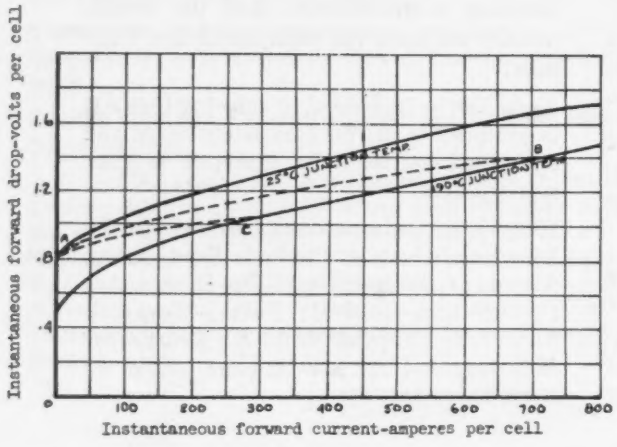

Fig. 2

INTRODUCTION

Demand for conversion of alternating current to direct current has been increasing at a rapid rate over the last few decades. In just a few years silicon rectifiers have risen to prominence in many of these fields where selenium, copper oxide, mercury arc tubes and motor generator sets were the predominant means of conversion. Total industry sales of silicon rectifiers have risen from $43 million in 1957 to $68 million in 1958 and a predicted $88 million in 1959. This rapid rise in the acceptance of silicon rectifiers is attributed to lower initial costs, smaller space and weight requirements, increased efficiencies, lower maintenance costs, and reduced cooling requirements. Manufacturing and development of the higher current germanium rectifier, a predecessor of silicon, has already been halted by some manufacturers of semiconductor devices in favor of concentrating on silicon device development. The main advantage of germanium, its lower losses in low voltage applications, has been offset by increased reliability and higher temperature limits obtained with silicon. One of the largest manufacturers of low voltage plating rectifiers has switched to silicon. In the middle voltage range where silicon and germanium have about equal efficiencies, germanium is no longer considered because of the larger number of elements required in series. Battery charger manufacturers have discarded selenium and germanium in favor of silicon. If all the battery chargers for which silicon rectifiers have been sold were connected in parallel, the total charging capacity would be over 5,000,000 amperes. In industrial and electrochemical rectifier equipment rated above 100 KW, over 87,000 KW of silicon rectifiers have been installed or placed on order within the last year and one-half.

RATINGS

Manufacturers' designs and ratings of silicon rectifiers allow the equipment designer much greater freedom in his choice of designs than any other type of rectifier. Rectifying cells are generally available as components that must be mounted on heat-dissipating surfaces. Some of the larger cells that are available are shown in Figure 1. Although the methods of rating will vary slightly from one manufacturer to another, there are, basically, only three characteristics that the equipment designer must consider for each application: forward drop, reverse voltage rating and thermal properties of the individual cell. The form of these characteristics are similar in all silicon rectifiers, and it is important that the designer understands how each of these characteristics affects the operation and reliability of his equipment.

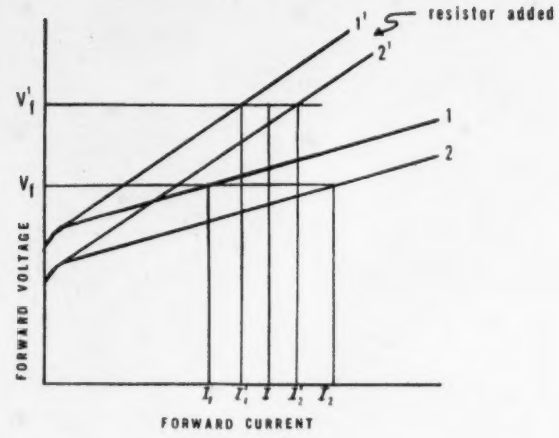

Fig. 3

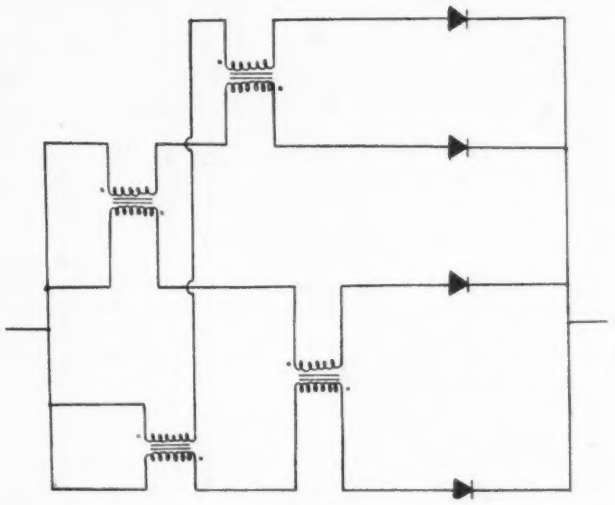

Fig. 4

FORWARD DROP

Instantaneous forward drop characteristics of a typical silicon power rectifier are shown in Figure 2. The solid line curves shown are for junction temperatures of 25°C and 190°C. If the cell is mounted on a heat sink the peak forward drop load characteristics, as a function of peak load current, are represented by the dotted lines from A to B and A to C. At very light loads the junction is closer to the lower temperature while at full load current it operates at the higher temperature. The line from A to B represents the load characteristics that would be obtained with maximum cooling and A to C, the load characteristics with the same cell and heat sink but with reduced cooling such as natural convection.

The slopes of these load characteristics are quite important in considering regulation and problems that may be encountered in paralleling cells. Variations in the characteristics of cells from any one manufacturer require that the forward drops be matched unless some method is used to force division of current between cells in parallel.

The simplest method of forcing proper current division among cells in parallel is to effectively increase the slope of a cell by the addition of series resistance. Figure 3 is an example of this effect. Current unbalance between two cells is reduced from I_2–I_1 to I'_2–I'_1. The resistors have the obvious disadvantage of introducing more regulation and more power losses into the equipment. However, the resistors do have the advantage of assuring a better balance during overload or fault conditions.

Balancing transformers, as a means of forcing proper current balance, have been the subject of several technical papers and articles. These balancing transformers, or reactors as they are sometimes called, consist of laminated iron cores, usually with single turn primary and secondary windings. The current from two cells in parallel pass through a core in opposite directions, and an unbalance between the two currents will induce a voltage which tends to correct the unbalance. One of the most commonly used arrangements of balancing transformers is the "chain" arrangement shown in Figure 4.

Separate transformers or transformer windings may be used to supply a number of assemblies each with only one cell in parallel. Then the output of these assemblies may be connected in parallel. If separate transformer windings are used, care must be taken in the transformer design. Multiple windings on any one transformer core will not necessarily have the identical leakage reactances required to force division of current between assemblies. For very

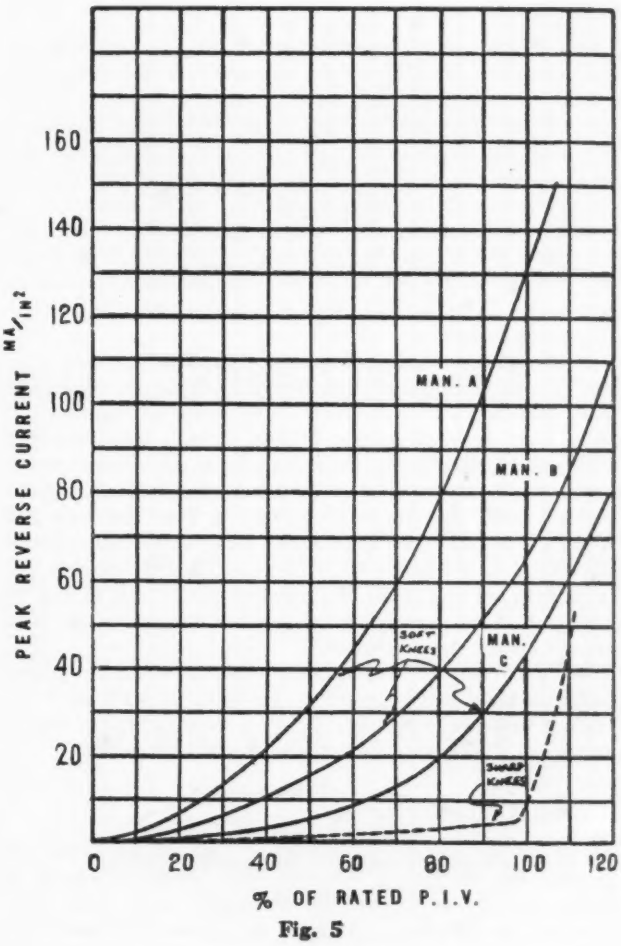

Fig. 5

large installations balancing transformers are quite often used to parallel cells in large assemblies which are then paralleled by the use of separate power transformers. Regardless of the method used to paralle the rectifying cells, differences in bus or lead reactance and resistance must be kept to a minimum.

REVERSE VOLTAGE RATINGS

Typical reverse voltage characteristics of silicon power rectifiers from three manufacturers are shown by the solid lines in Figure 5. These are commonly called "soft knee" characteristics. A typical "sharp knee" characteristic, more common in smaller area junctions, is shown by the dotted line of Figure 5. With either type of characteristic the reverse leakage current increases rapidly as the voltage is increased above the breakdown voltage. PIV (peak inverse voltage) rating of a silicon rectifier is commonly chosen close to the breakdown region. For this reason adequate safety margins must be allowed in applying silicon rectifiers to include any transients which might occur in the circuit. The manufacturer should be consulted to determine if transients above the PIV rating are allowed.

PIV ratings up to five or six hundred volts are available in higher power rectifiers while ratings up to 1,000 volts are available in the lower power rectifiers. The reverse characteristics of silicon rectifiers of any one type may differ considerably. Differences will exist in the magnitude of the reverse current, recovery time, and junction capacitance. For these reasons some form of voltage division is generally required. If the reverse characteristics are similar to those shown in Figure 5 the voltage across any one cell in a series string would be limited by the rapid increase in reverse current as the voltage increases. If the reverse characteristics do not exhibit a breakdown within a safe voltage rating for the cell, a destructive dielectric breakdown may occur. The manufacturer should be consulted for his recommendations.

With a large number of cells in series the recovery times and juction capacitances are more important considerations. Both resistive and capactive dividers may be necessary. A steep wave front of reverse voltage across a series string of cells will develop across the cell that has the shortest recovery time. (Recovery time is the time it takes to remove the carrier from the junction region so that the cell will block or support reverse voltage.) Stray capacitance in the circuit, if it is greater than the capacitance between the cells, may act as a shunt around most of the cells in a series string. A steep wave front of reverse voltage would then appear across one or two cells.

With capacitive and resistive voltage dividers, silicon rectifiers have been applied in applications with peak operating voltages as high as 70 KV. A series assembly with a maximum PIV rating of 30 KV is shown in Figure 6.

THERMAL PROPERTIES

As previously mentioned, no other type of rectifying cell permits the equipment designer the extensive choices of design he has with the silicon rectifier. Cells have been mounted on air-cooled bus bars, on water-cooled bus bars, on plates immersed in oil, and on a variety of plates and fins cooled by natural convection or forced air ventilation. Before the equipment designer can specify the mounting

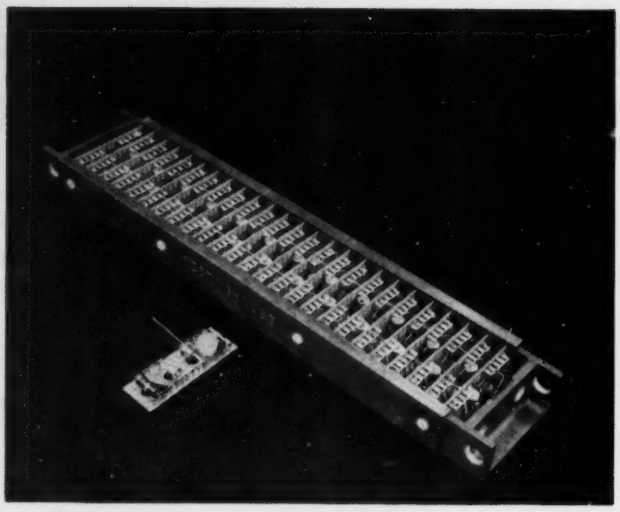

Fig. 6

he will use he must know either the maximum allowable junction temperature and internal thermal resistance of the cell or the maximum allowable case temperature at a particular load current. In either case the dissipated power must be known. If junction temperature is used then equation 1 would apply:

$$(1)\quad T_J = T_A + P_D\,(K_1 + K_2 + K_3)$$

where:

T_J = Junction temperature (°C)
T_A = Ambient temperature (°C)
P_D = Power dissipated by the rectifying cell (watts)
K_1 = Thermal resistance, junction to case (°C watt)
K_2 = Thermal resistance, case to heat sink (°C watt)
K_3 = Thermal resistance, heat sink to ambient (°C watt)

If case temperature is used then equation 2 would apply.

$$T_C = T_A + P_D\,(K_2 + K_3)$$

where:

T_C = Temperature of the case (°C/watt)

Either the maximum allowable junction temperature and internal thermal resistance or the maximum allowable case temperature are given on most manufacturers' data sheets. If the power dissipated at a particular load current is not given it may be approximated by equation 3.

$$(3)\quad P_D \cong I_{fwd} \times V_P$$

where:

I_{fwd} = Average forward current per cell (Amperes d-c)

V_P = Peak forward drop (volts)

Thermal resistance, K_2, from case to heat sink will vary with different types of cells and mountings. Thermal resistance, K_3, from heat sink to ambient is often specified for plates or fins of manufacturers' standard designs. However, if these standard designs are not used the equipment designer must consider carefully the fin or plate spacing, material and type of external finish he chooses. It is advisable to verify most thermal designs by measuring the case temperature of a number of cells in an assembly.

Since many different techniques are used to measure case temperatures, the manufacturer should be consulted for his recommendations.

Overload characteristics of a particular silicon rectifier are

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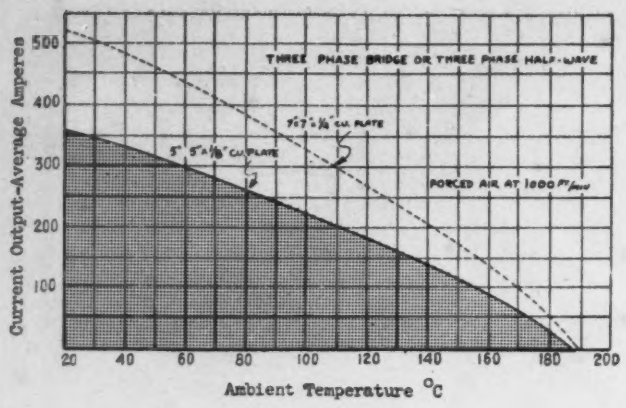

Fig. 7

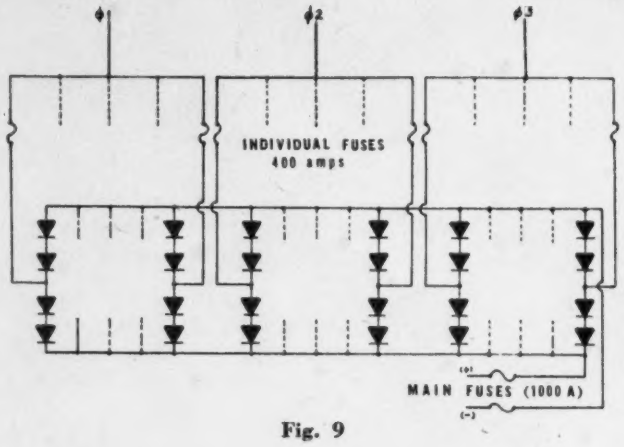

Fig. 9

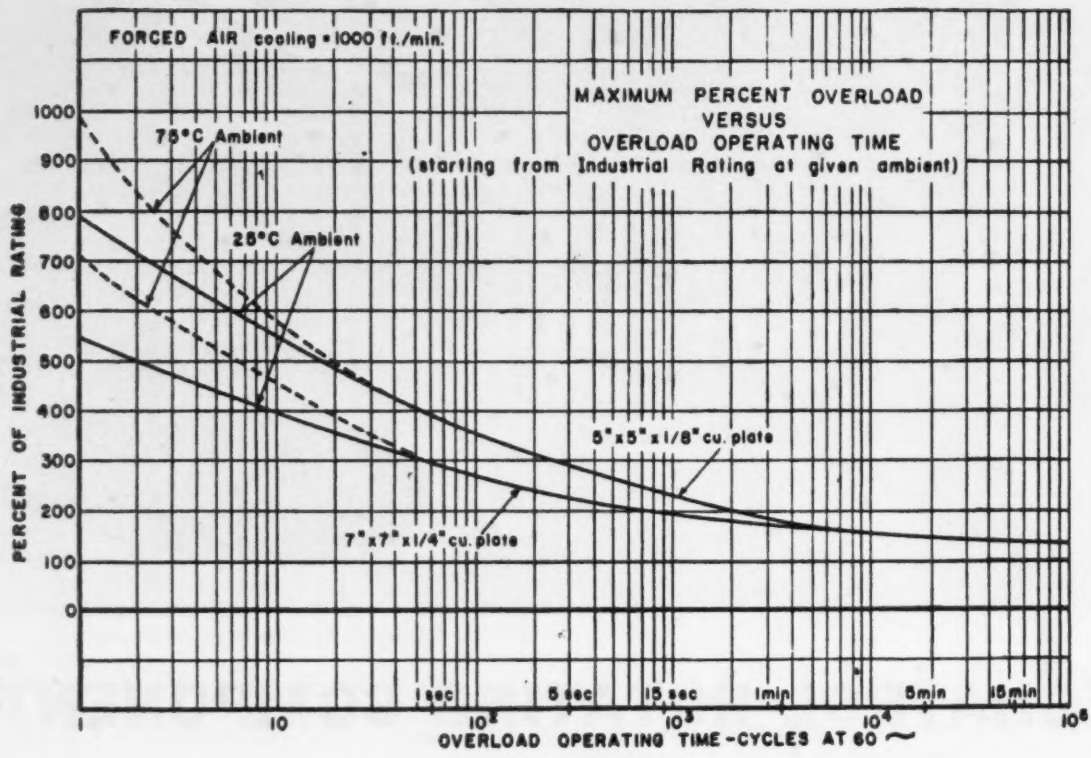

Fig. 8

largely dependent upon thermal design. Short time overloads in the order of a few cycles will depend upon the heat capacity of the material immediately adjacent to the rectifying junction. For times between a few cycles and about one second the heat capacity of the case is important. For longer overload times the heat sink on which the cell is mounted must be considered. Since the heat capacity of the silicon rectifier is quite small, the ratio between the rated load current maximum overload current will be small. The rated output currents of a three-phase bridge of silicon power rectifiers are shown as a function of ambient temperature in Figure 7. In Figure 8 the overload characteristics of this same assembly are shown.

PROTECTION TECHNIQUES

The protection to be used in a silicon rectifier circuit depends primarily upon the characteristics of the cells as just discussed, but the application requirements and individual preferences of the customer must also be satisfied. For this reason many techniques are used in both current overload protection and protection against overvoltage surges. These techniques vary from elaborate fusing and surge suppression schemes to no protection at all but, instead, the addition of a sufficient number of cells to withstand any possible overcurrent or overvoltage condition.

OVERLOAD PROTECTION

Overload characteristics as specified by manufacturers of silicon rectifiers generally refer to excessive load conditions which cause the rectifying junction to exceed its normal operating temperature. If repetitive overloads are a part of the normal duty cycle of an application, deterioration of the cell may occur and the manufacturer should be consulted for his recommendation. The overload curves may be used for specifying breaker and/or fuses as protection against the occasional overload. In the last few years, current limiting fuses have been developed which permit the designer to use silicon rectifiers at economical ratings and

Fig. 10

yet limit the short circuit currents to safe values. The characteristics of the fuses should be matched to the overload ratings of the cells and coordinated with other fuse or breaker protection.

In Figure 9 a fuse protection circuit is shown for five cells in parallel and two cells in series in a 250 KW, 250 volt supply. 400 ampere current limiting fuses are used in the a-c leads to each doublet in the assembly or a total fuse capacity of 2,000 amperes in each phase. 1,000 ampere fuses are used in the d-c output. Because of the higher total capacity in the a-c leads, an overload across the output will cause only the 1,000 ampere fuse to clear. If a cell within the assembly fails, one of the 400 ampere fuses will clear. The cells in this application are operated at about two-thirds of their maximum rated capacity. Figure 10 is a photograph of this supply showing the internal fuses.

Figure 11 is the simple circuit of a typical commercial battery charger. Although the continuous charging rate is 100 amperes, frequent short circuits with peak currents of 1,000 to 1,200 amperes are common. A small thermal breaker in the d-c output limits the time of this short circulit to approximately ½ second. Silicon rectifiers in this application must withstand repeated short circuits when leads to battery charger are reversed or accidentally shorted.

Figure 12 is a photograph of a 400 ampere, 40 volt d-c arc welder and the rectifier assembly it uses. Welders are not only subject to frequent load cycles but also to frequent short circuits as encountered when the welder strikes his arc. The test cycle for a typical welder bridge assembly is shown in Figure 13. The high series reactance of the welder will cause voltage surges as high as 300 volts when the arc is broken. The silicon rectifiers must withstand the repeated short circuits as well as the overvoltage surges.

OVERVOLTAGE PROTECTION

Overvoltage surges are common in most rectifier circuits. If the surges exceed the PIV rating of the silicon rectifier, a destructive breakdown of the reverse characteristic may occur. Figure 14 shows some typical rectifier circuits in which transient voltage surges occur.

With no load or an inductive load connected to the output of the rectifier, low energy switching surges will occur if

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1282	1/8	1/5	.05	100K
1284	1/4	27/64	.25	1 megohm

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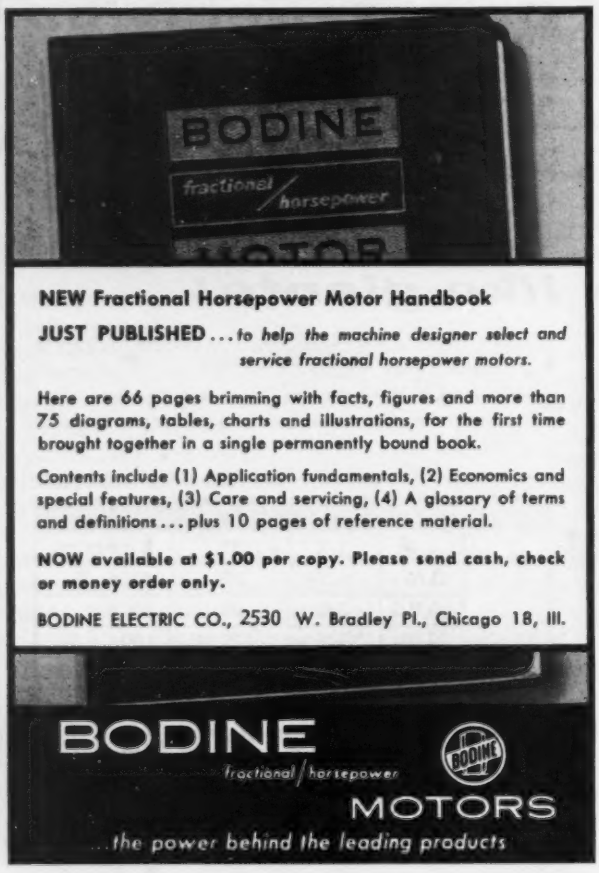
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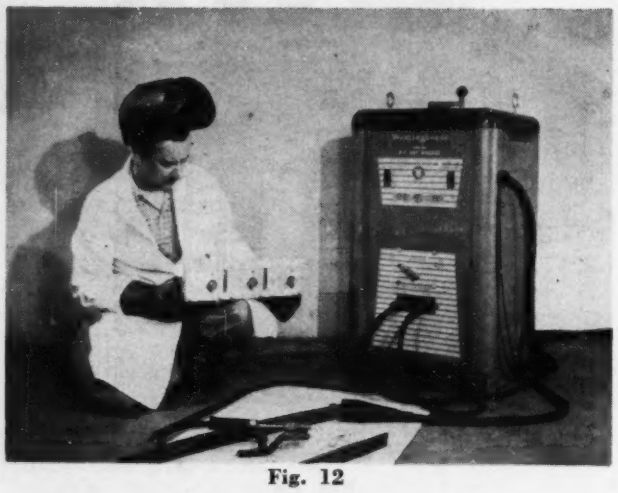


Fig. 12

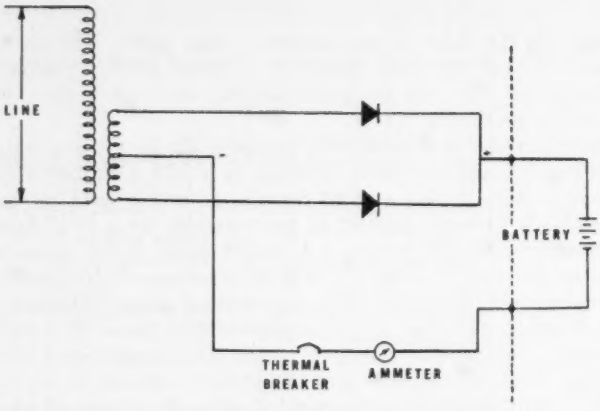


Fig. 11

the transformer primary is switched off or on. These surges result from the stored energy in the magnetizing inductance of the primary and from high frequency oscillations occurring in the tuned circuits formed by the transformer inductance and the stray capacitance of the transformer and circuit. Switching of the load current generally will not cause excessive overvoltage surges unless the source inductance is relatively high or unless a heavy overload is rapidly interrupted. Direct current motors are a source of surges caused by regenerative voltages if field control of the motor speed is used.

RC networks have been effective in reducing lower energy or voltage transients. A resistor and capacitor in series may be connected across the transformer secondary, across the cell in an assembly, or across a bridge output. In arc furnace applications frequent and rapid interruption of the arc causes transient overvoltages. The large amount of capacitance required in such an application requires that electrolytic capacitors be used across the output, but to reduce the ripple current through the capacitors and to prevent discharge of the capacitors into the load, the circuit of Figure 15 is used. The blocking rectifier in series with the capacitor allows the energy of the overvoltage surge to be absorbed. Overvoltage on the capacitor is then discharged by the bleeder, R_2. R_1 should be large enough to limit the

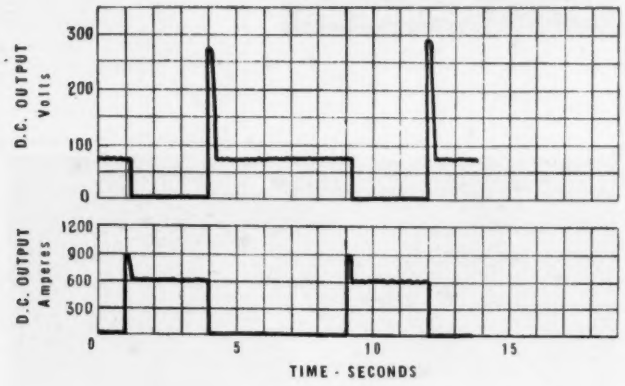


Fig. 13

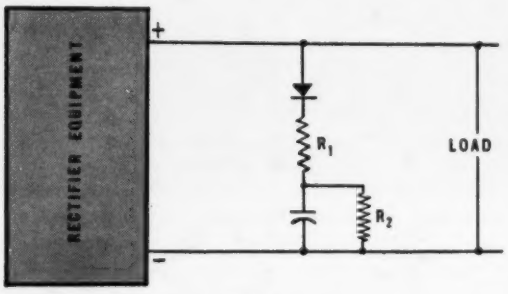


Fig. 15

initial inrush current to a safe value.

Non-linear resistors may be used as surge suppressors but are generally not effective on surges less than three times the operating voltage. A resistive load, electrolytic load, or battery connected across the output of a rectifier will reduce normal switching transients. Blocking rectifiers may be used in series with the d-c output of a rectifier to block the regenerative voltages or motor loads. In addition, other devices such as gaseous discharge tubes and selenium rectifiers have been used as surge suppressors.

RELIABILITY

Although the designer may be using the most reliable devices obtainable in his equipment he must consider the overall reliability of the completed rectifier assembly. As an example consider a three-phase bridge assembly with six elements. If the reliability, R_C, of each element is 0.99, the reliability of the assembly would be:

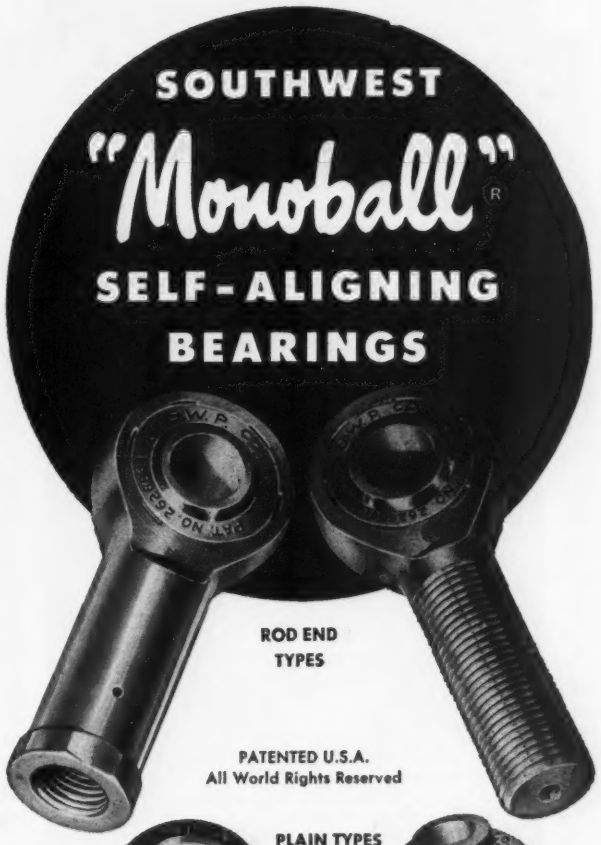
$$R_E = (0.990)^6 = 0.941$$

If six elements are connected in parallel the reliability of the paralleled group would also be 0.941 if the failure of one cell would result in an equipment failure. Six of these paralleled assemblies connected in a three-phase bridge would be a reliability of:

$$R_E = (0.941)^6 = 0.694$$

If the individual elements are fused and one additional cell is connected in parallel with the original six cells, the failure of one cell would not require a shut-down of the equipment. The reliability of an assembly of this type is then given by:

$$R_E = \left[\sum_{J=0}^{A} \frac{N!}{J\,(N!-J)!} P^J (1-P)^{N-J} \right]^X$$



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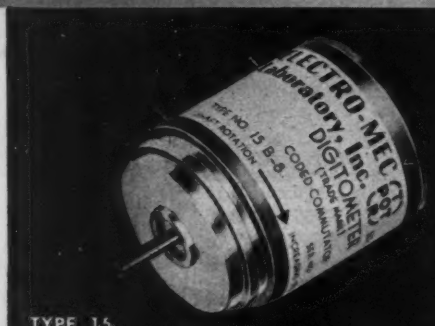

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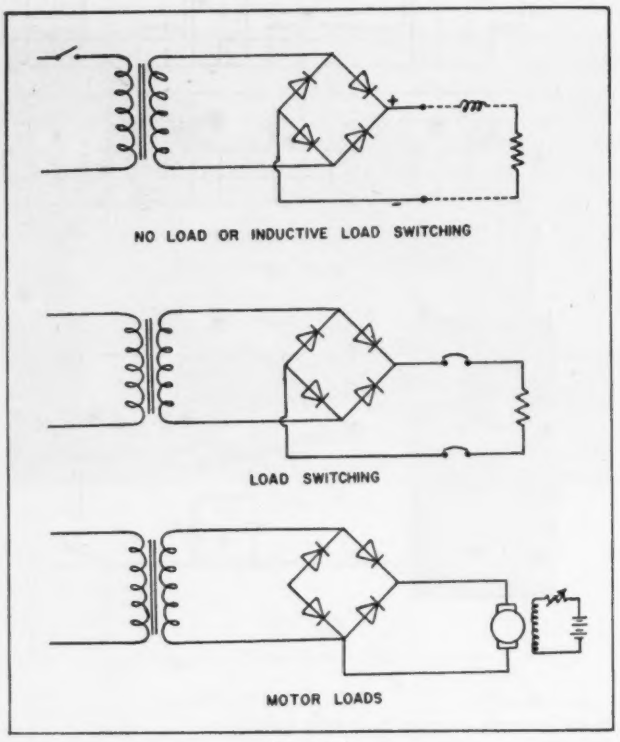

Fig. 14

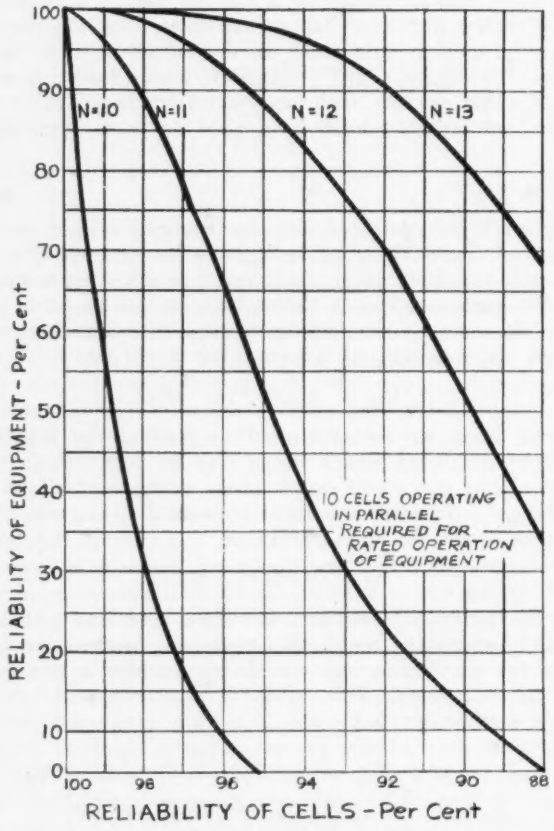

Fig. 16

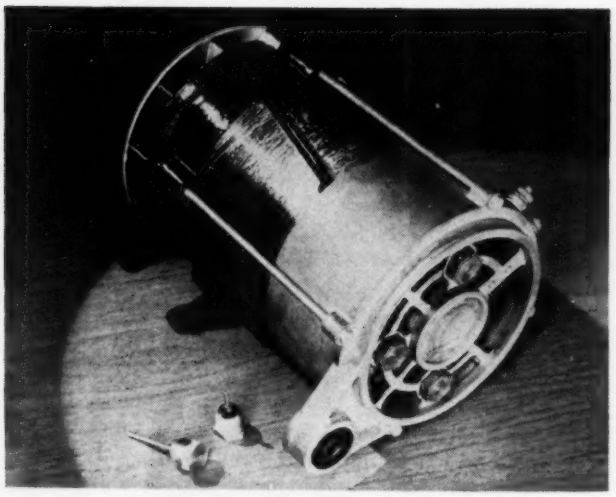

Fig. 17

where:

R_E = Equipment reliability

N = Number of parallel paths in each leg of an assembly

X = Number of legs in an assembly (three-phase bridge has six legs)

A = Number of cells in each leg which may fail with rated operation of the equipment still obtained

P = Probability of cell failure = $(1\text{-}R_C)$

R_C = Reliability of single cell

In this example, N = 7, X = 6, A = 1, and R_C = .99. Then R_E = 0.983.

Figure 16 is a family of curves showing the reliability of a bridge assembly as a function of the single cell reliability where ten cells in parallel are required for continuous operation and N is the actual number of cells used in parallel. Although the addition of extra cells in series, instead of in parallel, also increases the reliability of rectifier equipment, the added power losses may not be desirable.

CONCLUSION

Silicon rectifiers have, in just a few years, been used successfully in almost every type of rectifier application and in some applications where rectifiers could not previously be used. One of these new applications is the excitation of the rotating field in aircraft brushless alternators. The small size and high temperature characteristics of silicon rectifiers have made practical the automotive ac-dc generator (Figure 17) where the rectifying cells are mounted in the end plate of the generator. Figure 18 shows three aircraft rectifier supplies rated at 75 amperes, 100 amperes, and 150 amperes. Other applications include rectifiers for high voltage electrostatic precipitation, rectifiers for electrified railway cars, rectifiers for television power supplies, rectifiers for circuit breaker closing coils, and rectifiers for atomic reactor control rod supplies.

Further advancements in semiconductor rectifiers are expected. These include higher current and higher voltage

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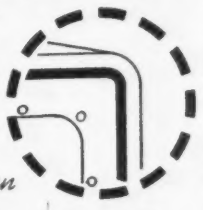

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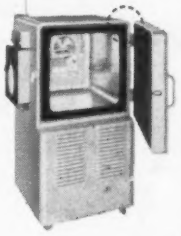

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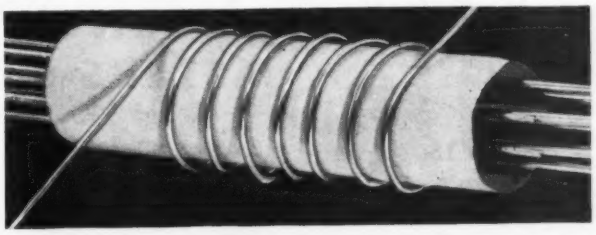

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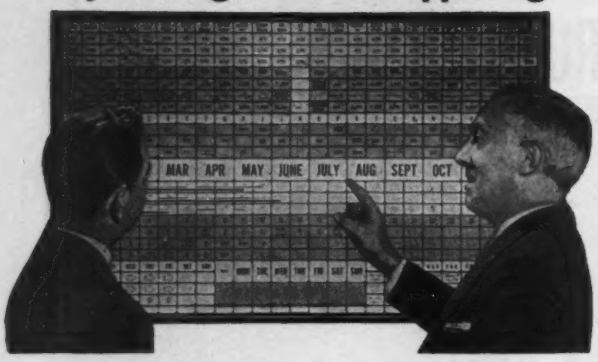

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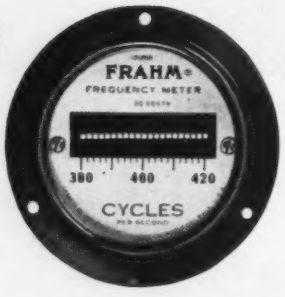

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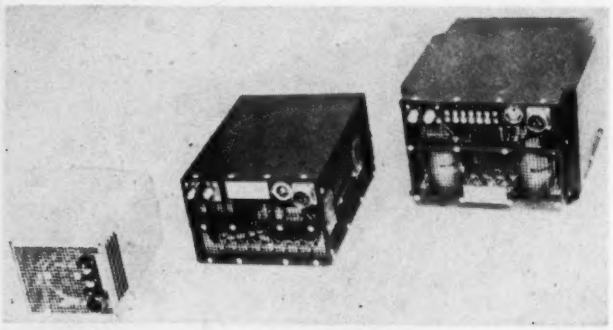

Fig. 18

junctions, higher temperature rectifiers and rapid progress in rectifier switches. Improved manufacturing techniques and expansion of the semiconductor market will continue to result in cost reductions. The vigorous activity of more than a dozen manufacturers of semiconductor devices is evidence of the bright future for silicon rectifiers as well as other semiconductor devices.

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Time Code Generator

Time code generator produces accurate timing signals during the recording of test data on magnetic tape. On playback from the tape, the recorded signals from the generator can be used to reconstruct test time for visual analysis and for automatic selection of test data for analysis by data processing equipment.

Consisting of a crystal-controlled oscillator and seven decades of frequency division, the generator produces 8 separate timing signals—100,000 to 0.01 cps. Use of a variable pulse width to code each timing signal permits mixing of signals to identify elapsed test time. Mixed output range is 100 to 0.01 cps on a single channel. Electronic counting and timing devices are used exclusively, including a time interval meter with an accuracy of ± 1 count ± short-term stability of ± 1 part in 10^6. The generator can be controlled from external electrical signals or contact closures to synchronize the timing signal with the start of the device being tested. Computer-Measurements Co., Sylmar, California.

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WORTH FILING

Electric Power Drives

Revised catalog expanded to 68 pages includes over 8000 ratings for a quick and easy selection of electric power drives. Data on a new line of drip-proof motors is given. Also included are dimensions and modifications for squirrel cage motors, gearmotors, speed reducers, right angle gearmotors, right angle variable speed drives and variable speed drives. Ratings are from ¼ horsepower to 200 horsepower. Variable speed drives range from 4660 rpm down to 0.2 rpm in variations from 2:1 up to 10:1.

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72-page catalog on a complete line of control devices contains horsepower selection charts for motors from ¼ through 200 hp, providing quick selection of starters, heaters, and push button stations necessary for control of these motors. Catalog also includes complete product description of motor starters both manual and magnetic, contactors, relays, solenoids, limit switches, push buttons, static control and pilot devices.

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Seals and Fasteners

16-page catalog describes a line of high-pressure, vibration-resistant seals and fasteners. Complete tabular data, specifications, brief descriptive text and engineering drawings are provided. Also described is a line of miniature, armored power connectors and a number of recently developed products: high-pressure removable gasket seals; boots for edge-lit or electro-luminescent panels and a flexible and tough glass-clear silicone material.

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Temperature Controls

29-page booklet describing the origin and operation of the snap-acting disc type thermal element, called the Spencer Disc. The publication details how the disc actuates thermostats, circuit breakers, and inherent overheat motor protectors, including a recently developed line of inherent overheat protectors for high performance motors. It also outlines other controls, not disc-actuated, such as motor starting relays, precision switches and thermal valves.

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Wire and Strip Components

Case studies of how design engineers were able to cut costs and improve quality through the use of wire and strip metal components are featured in a new design handbook. It also describes the major types of wire available for component construction, the most popular finishes, wire sizes and the variety of end treatments, threading and forming possible.

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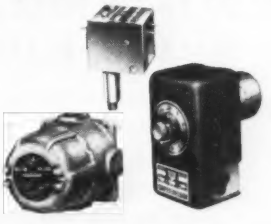

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Scientists at Tracerlab in Waltham, Mass. announce they have perfected a new chemical process for making sources of radioactivity that can be used with a far greater margin of safety than heretofore possible.

The new process actually makes a molecular or chemical cage for the radio-active gas, Krypton-85 by crystalling hydroquinone in the presence of gaseous Krypton-85. As the crystals form, atoms of Krypton become trapped within the interlocking network of resulting molecules in a material called a clathrate. If released the krypton contained in the cathrate would expand to approximately thirty times the original volume of the clathrate. The crystal structure does not interfere with the radiation emitted by the radioactive krypton but it does contain the krypton atoms just as effectively as a thick walled pressure cylinder.

In its gaseous state Krypton-85 has all but one of the properties radiation scientists desire in a radioisotope. It is a nearly pure beta emitter. The beta particles emitted have reasonable strength (695 kev max.). Its half life is moderately long (ie. 10.3 yrs.) and most important of all, krypton is an inert gas like helium and argon and thus cannot be stored or metabolized by the body like other radioisotopes. such as Strontium 90. But the fact that krypton is a gas has prevented its widespread use. Sealed containers for the gas are expensive to make. Large quantities of krypton can not be compressed to make a small source of high activity because this would require use of a thick walled container which would absorb most of the beta particles emitted.

The Krypton clathrate retains all the desirable properties of the gaseous krypton and eliminates this one deterent to its more widespread use. Another important safety factor is that if a clathrate material is spilled, decontamination can be accomplished by pouring water or ketone solvent over the effected area. This dissolves the clathrate crystals causing release of the krypton gas which rapidly dilutes and is carried away in the atmosphere. Tracerlab scientists say the possible applications of the new substance are virtually limitless.

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ALUMINA POTTING COMPOUND

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A paper describing how alumina powder (aluminum oxide) can be used successfully to insulate or "pot" electrical components within hermetically sealed cans was presented at the National Conference on Application of Electrical Insulation in Washington, D. C., by L. W. Kirkwood and R. S. Key of Bell Telephone Labs.

Popular conventional potting compounds include mineral-filled asphalts such as sand asphalt. This has good heat transfer properties, but it melts at the relatively low temperature of 135-150°C. When it melts, it expands, threatening the hermetic seal and often damaging the component. Alumina powder's melting point is over 1500°C, well above the operating temperatures of any electrical apparatus. It does not expand or contract to any noticeable extent under wide fluctuations of temperature, so no strains are imposed on the component. Also, it doesn't need to be cured or vulcanized for use, as some of the plastic potting compounds do, and thus no strains develop.

The powder possesses another unique advantage over asphalt epoxy resins, and other similar potting compounds, in that it maintains its dry, granular form in use. The electrical component can be removed for inspection or repairs simply by breaking the seal on the can and pouring out the powder. Alumina is completely inert, thus, there is no fire hazard, either during potting operations or in use.

The preferred physical form of the alumina is spherical. In this shape, the granules pack well and do not have the abrasive characteristic of more irregular shapes. Material of this type should be readily available at competitive prices.

The Bell Telephone test program on alumina potting compounds was performed on typical, medium-sized electronic power transformers, which were impregnated with a polymerizing varnish before potting and encasing.

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THE MAJOR BARRIER TO CREATIVITY IN INDUSTRIAL LABORATORIES

One of the most inhibitive factors for the establishment of a creative climate in the corporate set-up is the management philosophy that expresses itself in "creativity—within limits," or, "can't afford to take chances." In companies where this philosophy rules one finds that the challenges and problems given to technical people are either too specific and well defined, or too short range to result in the most creative contributions. The major emphasis in such companies is on introducing functional improvements on an already existing innovation rather than developing a completely new product or process. Those responsible in research for improving the product or process are asked to follow an orderly, direct, prescribed pattern in the process of pushing for a desired result. This type of emphasis on immediate payoff results in a meagre kind of creativity, which has its place for certain develoment work, but is extremely restrictive where basic research, or even advanced applied research are concerned. Management in many companies has still to learn to overcome its fear of the basic insecurity in fundamental research.

To find out how serious an "inhibitor" this attitude is in blocking creative performance in industry, the author, under the aegis of Industrial Relations News, an affiliate of Deutsch & Shea, Inc., technical manpower consultants, asked a panel of 105 authorities in the area of creativity to indicate their thinking on this point.

THE PANEL

The panel consisted of individuals who are connected in one way or another with either investigating creativity, teaching creative thinking courses, serving as consultants to industry in the area of creative research and management, or with direction of advanced research and development work. Many of them have made significant contributions in extending our understanding of creativity, and most of them have published articles and books on the subject. The sample included 32 individuals connected with various universities: 17 psychologists and social scientists, 2 psychiatrists, 7 professors of engineering and science; the others are in fields like industrial management, industrial relations, education, marketing, humanities, chem-

By Eugene Raudsepp

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istry and architecture. Eleven experts are connected with research foundations, independent research institutions and consulting organizations. The majority of the participants, however, are in industry: 33 serve as managers and directors of research and development, 16 are in charge of training and education and give courses in creative thinking techniques, 6 conduct personnel and management research and the rest are practicing scientists, chemists and engineers.

"CREATIVITY—WITHIN LIMITS"—THE MAJOR STIFLER

Over 72 per cent of the panelists felt that management attitudes of "can't afford to take chances," or, "creativity—within limits" are the greatest stiflers of creative achievement in industry. Another 9.5% felt that these attitudes are at least equal to other inhibitive elements in the industrial milieu. Following are some of the statements that illustrate the importance of risk-taking in creative research:

Dr. Melvin Thorner, Consultant in Research and Executive Personnel Problems, University of Pennsylvania: "Being conservative may be the greatest risk management can take."

Professor Silvan S. Tomkins of Princeton University: "I believe creativity without willingness to gamble is highly improbable—both for the individual and the sponsor."

Gordon C. Lange Executive Director of Swarthmore Creative and Development Services: "When a company adopts an attitude of security at all costs it has embraced the security of the jail and has imprisoned itself in its own cocoon."

Professor R. C. Jordan of the University of Minnesota: "The record speaks for itself. Those companies which have failed to encourage creativity have developed into copiers."

A communications executive: "High level management is quite often afraid to take chances, and therefore think they cannot afford to take chances, or dare to do something different. True creativity should have no limits except its own effectiveness."

Professor Franklin J. Shaw of Purdue University: "Creativity within limits is like being just a little bit pregnant. The creative spirit is an all or none proposition."

A psychologist: "The essence of original thinking is the willingness to take great 'chances in thinking'. A policy of caution in speculative thought can be deeply inhibiting of true creative thought."

Dr. Jules D. Porsche of Armour and Company: "These attitudes will not only limit the scope of creative work within the organization, but also discourage imaginative effort by generating a 'what the hell' attitude in the worker when he gets a brilliant or radical idea."

A staff engineer: "If the management attitude toward research is negative, or tends toward the over-anxious side, this could stifle the results of a creative team. If the management of a company does not believe in the possible benefits that can come from research, it would be better not to organize such a group within the company."

Dr. Brewster Ghiselin, author of the book "The Creative Process": "Creativity, like everything vital, involves taking some chances. It can't be realized 'within limits', because it cannot be prescribed. Creation always takes a fresh course to an unforeseen end."

PROFIT MOTIVE LIMITS PERSPECTIVES

Implicit in a large number of panelists' comments was the notion that management is primarily concerned over profits and therefore cannot see the value in the long-range, expensive, unpredictable and intangible results of fundamental research. This concern over profits was spelled out explicitly by the following panelists:

A manager of development engineering: "If creativity is wanted by management, then management must be prepared to gamble and pay for ideas which don't work out. They should also recognize the ones which are successful. If management insists on a sure thing, then there is little room for creativity as such. 'Creativity within limits' must produce limited results, depending upon how tightly the reigns are drawn."

Dr. Fred C. Finsterbach, Educational Specialist: "As long as management has to show a profit the chances they can afford to take will be circumscribed by this motive."

Hyman Kirtchik, Chemical Specialist, General Electric Company: "This is true and varies with the cycle of business dollars available. In many instances the amount of research effort is reduced or business is reduced. In a large company, at least, a sinking fund should be set up so that research is *stepped up* during internal recession periods. In this way one can keep up with competition and seek new products to overcome subsequent recession periods."

W. F. G. Swann, Director of Bartol Research Foundation: "Any organization which works on the basis that it can't take chances is doomed to failure. The thing to do is to set aside a certain appropriation for research and avoid the feeling that any individual activity in the program as a whole is one to be estimated in terms of chances of making a profit. If one considers some of the great industrial research laboratories such as General Electric Company or Bell Telephone, one finds that one or two researches performed in those laboratories have provided enough basis of financial return that it would be possible on the basis of it, and without loss to endow the research laboratories for all time even if they never made one new accomplishment from now to eternity. One can only evaluate the monetary value of fundamental research when integrated over such a long period that any particular research itself is apt to loose its meaning in the program as a Whole."

THE PARALYZING INFLUENCE OF FEAR OF FAILURE

In the success-oriented career of management failure looms large. Yet failure is part and parcel of creativity. A policy of caution because of fear of the consequences of failure, or because of the fact that "management people are not permitted to make mistakes," can only lead to limited creativity. Professor Harold R. Buhl of Iowa State College suggests that "we must make it possible to try our ideas without the failure being fatal."

The specter of failure casts such a fearful shadow over management also because of the importance imputed to judgment ability in their office, and the pride they take in this ability. Yet it is this supposedly all-important asset of top management that curbs their willingness to take the risk or chance that a leap into the unknown involves.

RESISTANCE TO CHANGE

Another reason why management often circumscribes creative research, why it prefers the ponderous security that it finds in slow but sure research and development along prescribed lines, rather than the greater promise in unpredictable creative leaps, is their resistance to change. As professor Leo B. Moore of M.I.T. stated: "For managements generally creativity means change and change means trouble—so let's not have too much of it."

The clearly defined, the securely determined and established have a much more powerful hold on managements, as a rule, than the new, which often threatens to disturb the security of the status quo. Consequently the engendered conflict between the old and secure, and the new and unaccepted, more frequently than not, ends with the victory of the conservative impulse to side with the familiar, realized order of circumstances. It is for this reason that we find management building up comfortable, smoothly operating systems or channels in which to operate, which they can take for granted, and into which their sense of stability can easily flow and solidify. It is for this reason that the preference for small, predictable and orderly improvements, rather than radical change, remains paramount.

Several panelists felt that research people themselves could modify somewhat this conservative and conformist character of management attitudes if they could sell them the idea that creative research "can supply its own breaks without stifling creativity," and that they are themselves "capable of judging the chances of success." If, in addition, they can show that they have "a good appreciation of economics," or, as a director of engineering put it, "they are quite willing to accept the feeling that the purpose of the laboratory is in the long run to make money for the company and not just to furnish a hobby shop for the worker," then management might begin to learn the value in "blue sky" projects. One panelist also pointed out that researchers should learn that "administration, at least the good ones, are not exploiters of research people, but are merely creative people in another field, i.e., administration."

LIMITS ARE MANDATORY

There were quite a number of panelists who felt that limits are mandatory in the industrial research environment. These were some of the reasons given:

George S. Pettee, Assistant Director of Operations Research Office: "In work for any organization the creative is a far wider category than is the useful. The most 'creative' workers all too often originate things that cannot be of interest to the organization with its specific scope. So, inevitably, no management ever is or can be in a position to encourage and appreciate the 'creative' without restriction. One advantage of the bigger over the smaller organization is that it can use a wider range of creativity. Only the university, and only after picking the men, can use it freely."

A manager of research and development: "I suspect that most of the time it is a case of the little dog on a leash, barking 'let me at him'. Management must often limit its immediate goals. A good man will make the most of it, putting down on paper what he can't actually make."

Dr. F. A. Cartier, Educational Specialist: "Management must obviously set limits upon the dreams of the creative man, and obviously must not take wild chances. These facts of life must be understood by the creative personnel."

A REBUTTAL

Perhaps the best answer to those who want to circumscribe creative research, especially of the basic character, is contained in the comment Professor Robert P. Crawford of the University of Nebraska made:

"The fundamental difficulty is that management feels it has some definite end that must be accomplished. It wants all creative effort directed toward that one invention or process. This implies that all creativity should be problem solving, according to management. But this neglects one of the great ends of creativity—the discovery of all sorts of things and processes. Coal tar dyes, carborandum and penicillin were only side issues to the task that seemed valuable at the moment. This suggests that top management must be creative, otherwise it will be tying its creative men down to problems that may or may not be valuable. A good administrator must be a man who sees significance in what is before him."

SUMMARY

The unpredictable nature of the creative process makes it alien and often suspect to management. The majority of the panelists offered many instances where management's insistence on order, predictability and profits provided a procrustean bed for the creative researcher. While several acknowledged the necessity of "creativity within limits," they warned that the limits were too often set by management's developed conservatism, its preference for the familiar, its overemphasis on quick returns, its fear of change.

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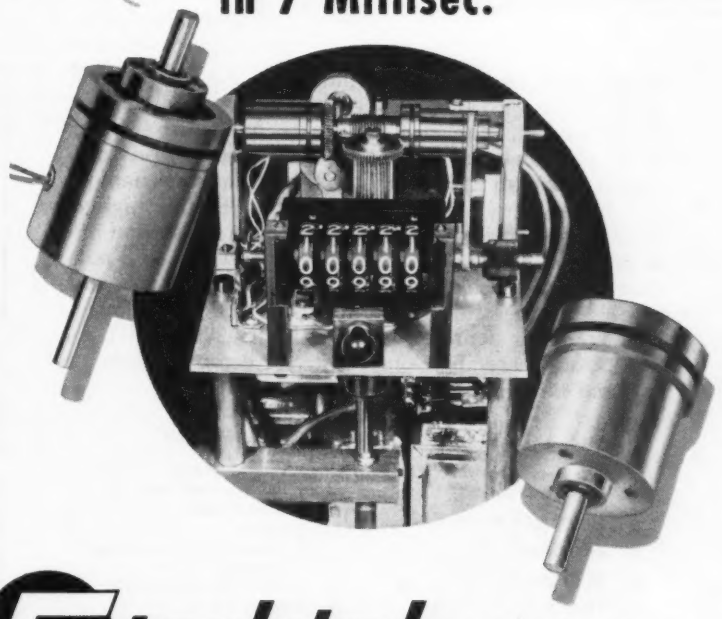

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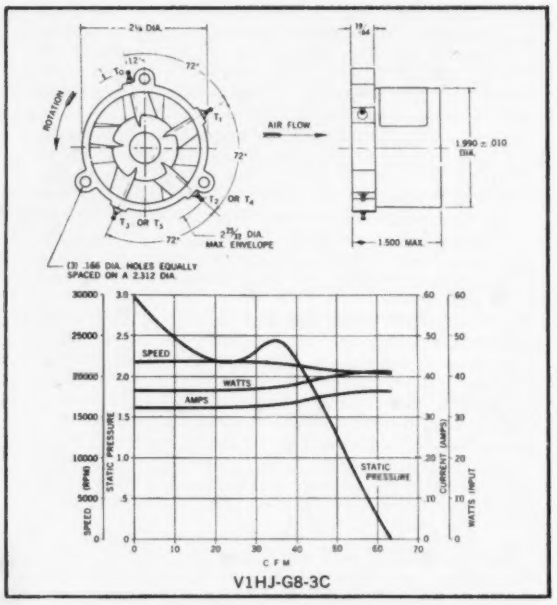

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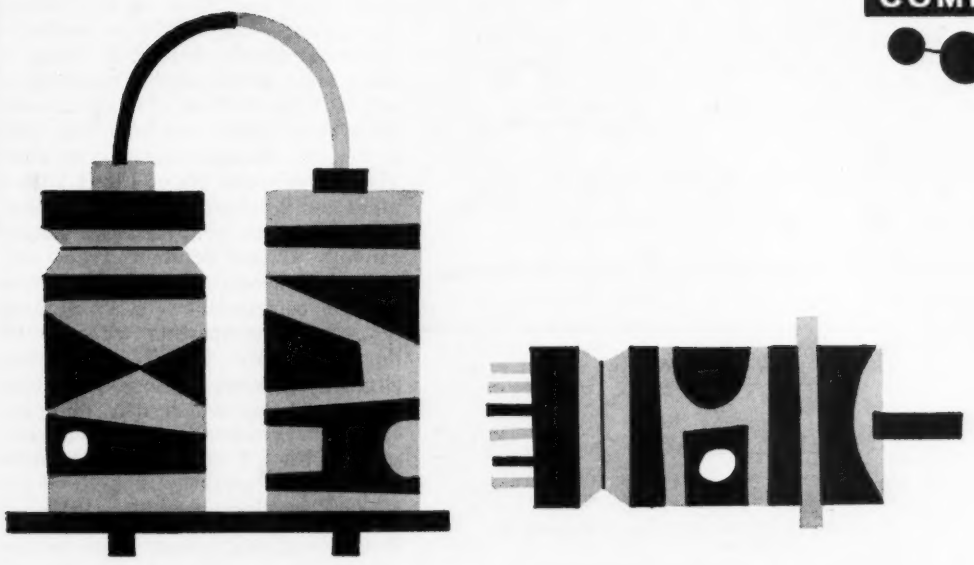


ELECTRICAL RESOLVERS

Electrical resolvers are electro-mechanical transducing devices which develop an output voltage proportional to the product of an input voltage and the sine of the shaft angle. Some resolvers have two inputs and perhaps two outputs, in which case the individual outputs are determined by superposition of the separate input contributions. Fig. 1 defines the most general resolver characteristics. Figs. 2 through 4 show common applications of the resolver in computation, based upon the defined properties of Fig. 1.

Because of their ability to generate sinusoidal functions readily, resolvers are widely applied in computers where they perform such operations as rotation of coordinates, converting between rectangular and polar coordinates, solution of plane and spherical triangles, generation of tangent functions (by means of a dividing servo-mechanism) and similar often required computations. They are particularly useful in navigational computers and gunfire computors where trigonometric relations frequently occur. Resolvers frequently appear in specialized instrumentation where empirical data suggest use of a sinusoidal function. Special applications include phase shifters, sweep generators, harmonic analyzers and similar devices. Resolvers may be used in angle transmission systems where single-speed accuracies to 2 minutes are required.

In the most general applications, the two input, two output electromechanical induction resolver defined in Fig. 1 is a marvel of simplicity, replacing bulky computer assemblies which have been heretofore required. As a matter of fact the development and refinement of this type of resolver has constituted a major step in the simplification of military analog computers, hastening the transition from slow heavy mechanical computers to the miniaturized electromechanical varieties of today.

Although not nearly so popular for precision applications, the use of a special resistance potentiometer as a resolver offers some advantages. Of

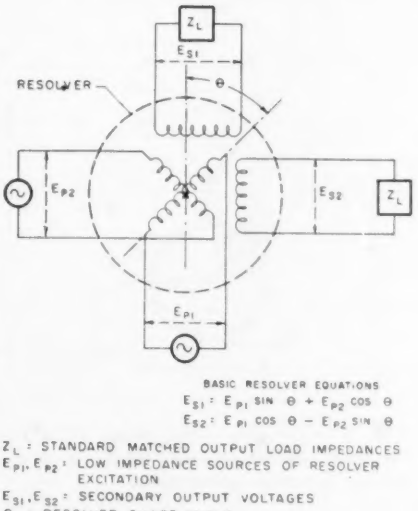


Fig. 1 Definitive characteristic of 4-winding electric resolver.

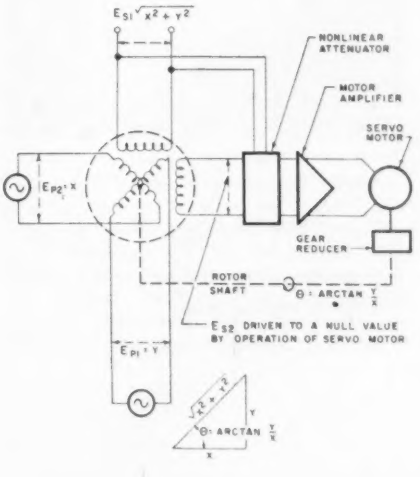


Fig. 2 Using a resolver to convert from rectangular to polar coordinates.

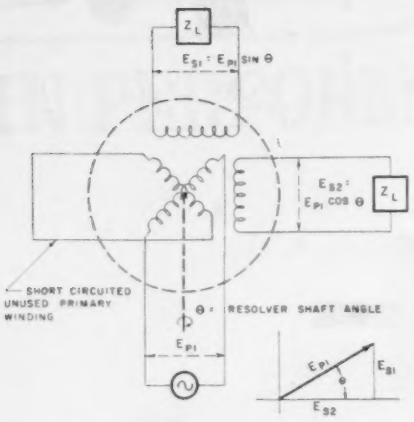


Fig. 4 Converting from polar to rectangular coordinates with an electrical resolver.

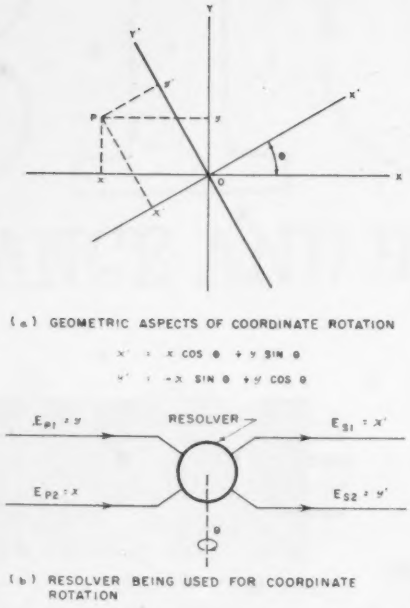


Fig. 3 Resolver application in rotation of coordinates.

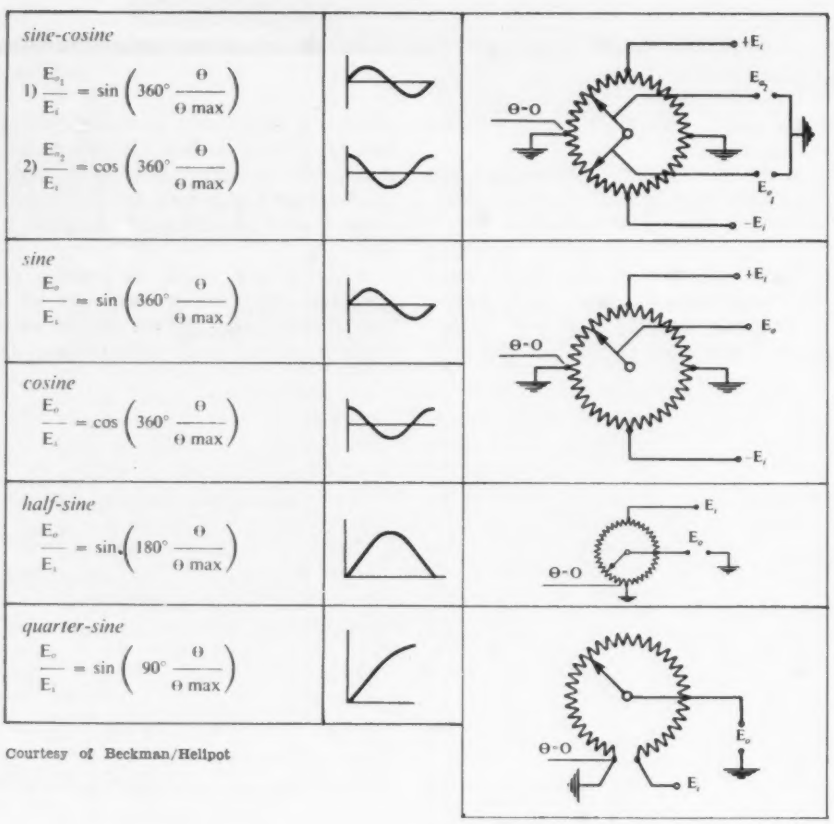
particular importance are its suitability for d-c applications, and its freedom from phase-shifts and residual (null) voltages. On the negative side, noise at the brush contacts, higher friction, relatively poor resolution in wire wound types, shorter life, and lower maximum operating speeds, reduce its value in many applications. Highly accurate resistance type resolvers of large diameter (6 or more inches) are frequently used in general purpose analog computers. The general resolvers of Figs.1 with 2 input and 2 output windings is equivalent in function to at least two ganged carefully aligned resistance-type units.

Fig. 5 shows schematically some possible configurations of a resistance resolver for comparison with the induction variety. Fig 6 shows some alternative means of sinusoidal function generation which may offer advantages in certain special circumstances. Figs. 7 and 8 illustrate some of the less general applications of the resolver, supplementing Figs. 2 through 4.

FUNDAMENTALS OF ELECTROMECHANICAL RESOLVER PERFORMANCE

Fig. 9 shows the internal construction of the electromechanical resolver. Note its resemblance to an electric motor, specifically a two-phase, two-pole wound rotor induction motor with slip rings. Actually the difference is only in details of the design and the degree of refinement required in manufacture.

As in the conventional two-phase machine there is a wound stator assembly and a wound rotor assembly. Windings are placed in the insulated slots of laminated high permeability magnetic cores. The design of the windings is such as to give a close approximation (within a small fraction of a percent) to a sinusoidal variation in mutual inductance between individual rotor and stator windings with uniform rotation of the shaft. The relative location of the two stator windings (and the two rotor windings) is such that mutual coupling is zero. Thus, a rotor winding may only couple a stator



Courtesy of Beckman/Helipot

Fig. 5 Common connections of a resistance potentiometer used in sine-cosine function generation.

Fig 6 List of alternative means of electromechanical sine-wave generation.

(a) Cam and follower coupled to pick-off.

(b) Sinusoidal gearing coupled to output potentiometer.

(c) Mechanical linkage mechanism, such as Scotch Yoke, driving pick-off.

(d) Internal gearing arrangements for generating sinusoidal motions.

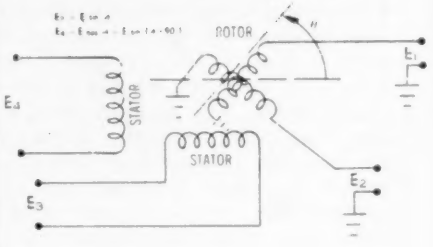


Fig. 7 ***Resolver used as phase-shifter.*** **A resolver can be connected in several ways to provide a variab'e amount of time-phase shift. The circuit of this figure provides variable time-phase shift when two voltages separated 90° in time phase are available. The resolver output is:**

$$E_1 = E_4 \sin\theta + E_3 \cos\theta$$
$$E_2 = E_4 \cos\theta - E_3 \sin\theta$$

with $E_3 = E \sin \omega t$

and

$$E_4 = E \cos \omega t = E \sin(\omega t + 90°).$$

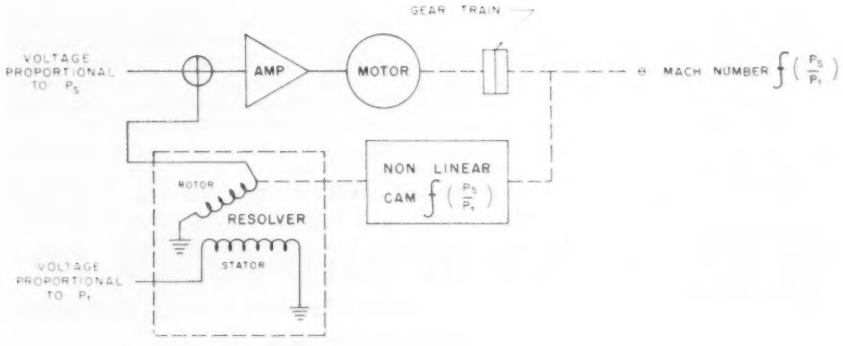
These equations become:

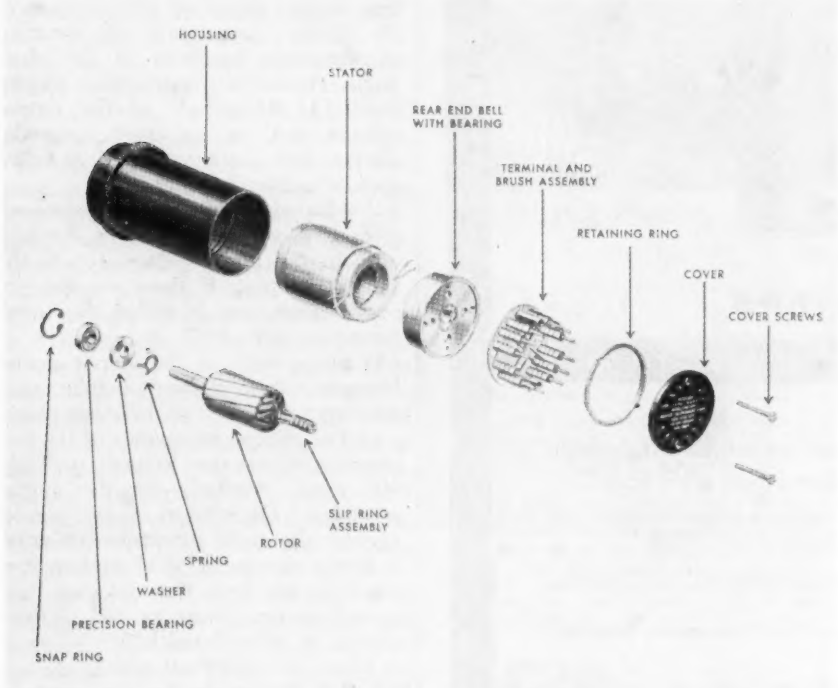
$$E_1/E = \cos \omega t \sin\theta + \sin \omega t \cos\theta = \sin(\omega t + \theta)$$
$$E_2/E = \cos \omega t \cos\theta - \sin \omega t \sin\theta = \cos(\omega t + \theta)$$

and hence E_1 and E_2 can be shifted in time phase simply by rotating the resolver. One interesting use for this phase shifter is in the frequency response testing of feedback control systems. The phase shift of a device under test can be measured directly by comparing the sinusoidal output from the system with the phase shifted output from a resolver on an oscilloscope. For each reading the phase shift of the two signals are made equal by adjusting the resolver shaft. The inphase condition is noted on an oscilloscope and the system phase shift can be read direct'y from a calibrated dial on the resolver.

Courtesy American Electronics, Inc.

Fig. 8 Resolver application in Mach computer. The output shaft position varies proportionally to mach number which is functionally related to the ratio of pilot pressure (P_t) to static pressure (P_s). The functional relationship is built into the cam. The resolver output varies sinusoida'ly rather than linearly; thus the cam is additionally shaped to linearize the effect of the resolver. In this application the resolver provides superior accuracy, reliability and life over a feedback potentiometer. In order to provide the proper scaling, a precision transformer is usually required to excite the potentiometer. This is not necessary with a resolver since the transformation ratio can be adjusted to provide correct scaling.





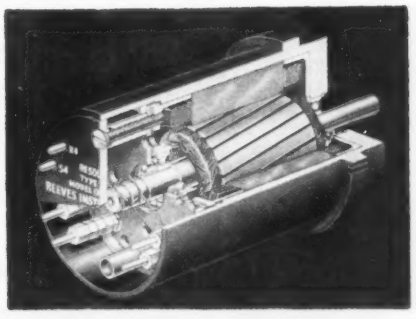


Fig. 9 Internal construction and exploded view of a Reeves Instrument Corp. precision electrical resolver. The input windings are on the stator. The lead-in wires for the rotor, which has the output windings, are connected through slip rings since the rotor revolves on precision bearings.

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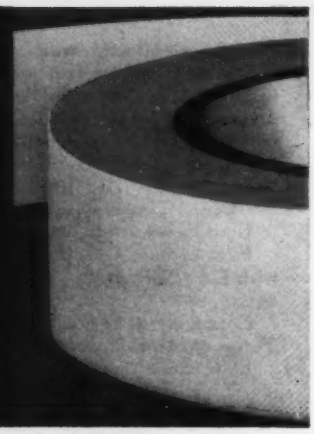

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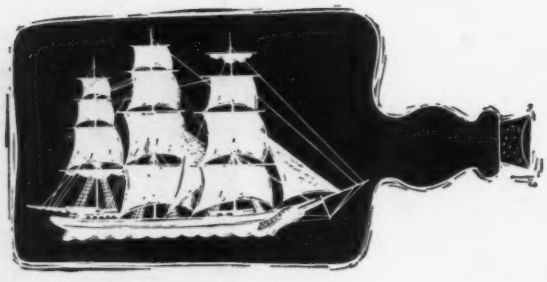

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winding, and vice versa.

The similarity in construction between the resolver and a small electric motor suggest that notwithstanding its high precision and the presence of slip rings, it is essentially a rugged device, capable of operating reliably in severe environments. This is quite true, the slip rings being perfectly satisfactory for long life (thousands of hours) at speeds to several thousand rpm. By contrast this is manyfold more reliable than comparable, wire-wound resistance type units. The electromechanical induction resolver can meet the environmental requirements generally expected in computer equipment for military use.

Environmental requirements have a special significance in connection with electrical resolvers. Not only is it necessary that the unit survive essentially intact; but also, its precision must be maintained. To maintain precision, careful control of dimensions and fits are necessary over the entire specified range of ambient temperature. Temperature coefficients of the major structural members must be matched to avoid differential expansions which may cause sloppy fits or strains of interference. For example the mismatched coefficients of expansion between a housing and a stator lamination stack may introduce an interference at some temperature extreme which will distort the lamination stack resulting in a shift in electrical axis.

THE IDEAL RESOLVER

The ideal resolver possesses the definitive characteristics of Fig. 1, namely the precise generation of specified trigonometric functions of the shaft angle. Precise output functions require that: (1) Magnitude of the output voltage vary in an exact sinusoidal manner with shaft angle. This is called *angular accuracy.*

(2) Maximum output voltages of all secondary windings bear a constant ratio to the input voltage (or to the vector resultant, if there are two inputs). This ratio is called the transformation ratio, or T. R.

(3) Phase angle of the output carrier frequency bear a fixed angular relationship to the input or reference phase.

(4) The axes or zero points of the two input windings be located precisely 90° apart. Similarly for the output windings. Departures from perfect angular alignment constitute *axis error.*

These aspects of ideal performance establish the basis for defining individual resolver errors as will be considered in more detail later.

There are additional impedance factors that characterize the ideal resolver, and more or less the actual resolver. If a resolver has two primary and two

secondary windings in the most general case, then:

(1) The input impedance of any input winding is constant, independant of shaft angle, provided that both secondary windings are terminated in balanced loads.

(2) The output impedance of any secondary winding is constant, independent of shaft position provided that both primaries are energized from sources having equal internal impedances, preferably close to zero.

To achieve guaranteed accuracy it is necessary that primary and secondary impedances be balanced. These points are proven mathematically in Table 1. When only one input and/or output winding is employed, the unused windings must be properly terminated. In practise it is common for the unused input winding to be short circuited while the other winding is energized from a low impedance source. Secondary windings are generally terminated in a standard relatively high impedance load which may be a dummy load, or a combination of a natural circuit termination plus a trimming impedance to match the standard load. Normally the standard load includes a shunting capacitor, since some shunting capacitance may be unavoidable in the application circuitry.

NONIDEAL ASPECTS OF PERFORMANCE

In actual practice the electrical resolver performs in other than an ideal manner. To make the best use of commercially available units, these nonideal aspects of performance and the errors to which they lead must be clearly understood.

Consider first the nonsinusoidality of the output voltage versus shaft angle function. Because this function is determined by the variation in mutual coupling between the energized primary and the secondary, the distributions of the primary and the secondary windings are of critical importance. The primary winding must develop a flux density distribution in the air-gap between rotor and stator as close as possible to a sinusoid. The principle limitation is the finite number of slots which of necessity leads to a step-like approximation to the required flux density distribution, with discontinuities corresponding to each slot. The secondary winding must be so distributed as to minimize its sensitivity to harmonics present in the flux distribution wave form generated by the primary. By matching primary and secondary distributions, unavoidable primary harmonics may be cancelled or minimized by suitable secondary configurations. The secondary need not

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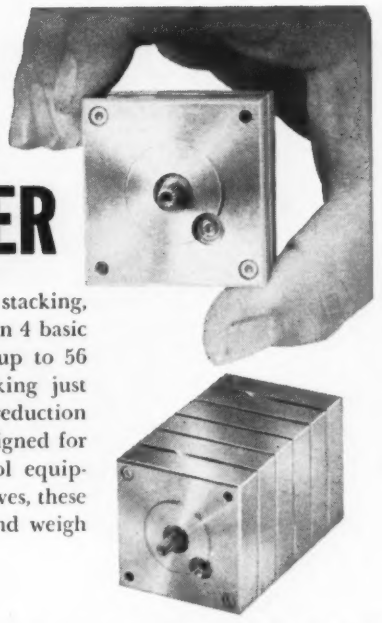

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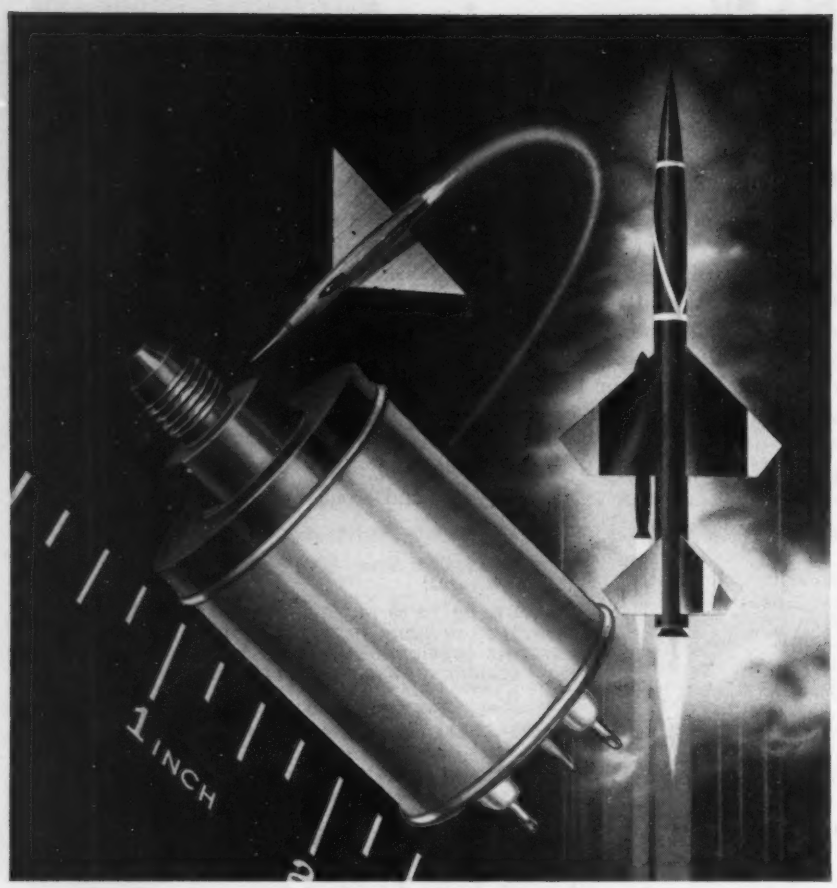

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TABLE I

Output Impedance Relations in Induction Resolvers

Choose any primary or secondary winding. Assume the opposing pair of windings is terminated in balanced impedances (which may have the value of zero). Let Z be the total impedance of the windings of the balanced pair; let X_M be the maximum coupling impedance between the chosen primary or secondary winding and the individual opposing windings. Then the coupled impedance, by basic a-c theory is given as:

Coupled impedance $= [(X_M \text{ Sin } \theta)^2/Z] + [(X_M \text{ Cos } \theta)^2/Z]$

Simplifying:

Coupled impedance $= X_M^2/Z$, a constant. Thus the input and output impedances of a properly balanced resolver are constants, independent of shaft rotation.

TABLE II

Winding Rules for Electrical Resolvers

Accurate electrical resolvers generally have the coils on their rotors and stators arranged so that the number of coil sides in successive slots follow a sinusoidal pattern. This pattern provides the best possible accuracy, eliminating all harmonics of the fundamental flux wave except the so-called slot harmonics. Slot harmonics are defined as those harmonics having an order equal to an integral multiple of the number of slots, plus or minus one. Slot harmonics occur in pairs as shown below for a 12-slot lamination.

Slot harmonic orders: 11, 13; 23, 25; 35, 37; etc.

The ratio of slot harmonic to fundamental is the reciprocal of the order of the harmonic. This attentaution factor applies equally to the primary which generates the harmonic, and the secondary which picks up the harmonic output voltage component.

For maximum accuracy it is apparent that the choice of primary and secondary slots is critical. Since theoretically only those slot harmonics of the primary which are also slot harmonics of the secondary will contribute to the output (error) voltage, the slot combination should confine common slot harmonics to as high an order as possible. A 12-slot, 20-slot combination for examples has the 59th and 61st as the lowest order common slot harmonics.

Skewing can minimize but not eliminate slot harmonics. There is a theoretically correct skew for minimizing any pair of slot harmonics. This skew or any multiple of this skew is suitable. In the above example, one slot pitch of either the 12-slot or 20-slot member would be a satisfactory skew.

The effect of slot openings is primarily to affect the magnitudes of the slot harmonics. They contribute no *new* components to the error pattern.

TABLE III

Space and Time Harmonics

Space harmonics are harmonics in the distribution of flux in the air-gap of the resolver. They may be determined as a percent of fundamental by a Fourier analysis of the flux distribution pattern. Space harmonics cause angular inaccuracy. *Time harmonics* are high frequency components generated by nonlinearity in the resolver magnetic circuit. In a-c resolvers with no d-c components present, time harmonics are odd multiples of the fundamental frequency. Time harmonics appear as a component of null voltage.

particularly discriminate against harmonics not present in the primary waveform.

Table II lists some rules for matching windings in electrical resolvers. Table III, provided for reference only, clarifies the important distinction between space and time harmonics.

Transformation ratio and phase angle errors may be considered together. Assume for simplicity a resolver with a single primary winding and a single secondary winding oriented for maximum coupling. The secondary to primary voltage ratio is the T.R. and is usually precisely defined. The secondary to primary phase angle is called the phase shift and is normally leading. T.R. and phase shift taken together constitute a *complex* transformation ratio.

In normal production neither the T. R. nor the phase angle occurs as a precise quantity. *Standardization* procedures, described below, may be used to adjust these quantities to a small fraction of a percent and several minutes of angle respectively with respect to a prescribed standard value. Standardization adjustments are usually carried out on the primary circuit(s). What is important in the production resolver is that secondary windings be matched so that a primary winding will have the same complex T.R. as it is coupled in turn with the separate secondaries. Furthermore, variations in T.R. with temperature, line frequency and input voltage level must be as small as possible. In precise units means must be provided to maintain T.R. and phase shift constant in the face of all these variables. The elaborate compensation circuits used with the most accurate resolvers are primarily designed to prevent variations in T.R. and phase shift. It is generally true that if these are constant at the prescribed standard values the angular accuracy requirements (functional conformity) are relatively easy to meet.

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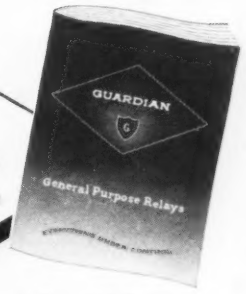

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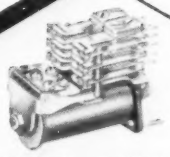

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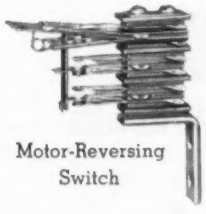

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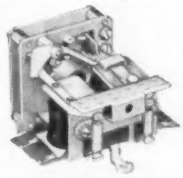

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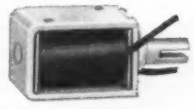

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23M6B1	Size 23	Resistor Compensated Resolver
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COMPONENTS DIGEST

Thus, the output at any angle from a zero point equals the complex T.R. times the sine of the angle, with only a small nonsinusoidality error.

In the most accurate units, the variation in the complex transformation ratio with line voltage, frequency, and temperature variation must be held to an absolute minimum. It is because of these variations that complex compensation circuits have been developed. While these circuits are discussed in a later section, it is important to understand the sources of error which require such compensation.

Since the resolver is considered for the special shaft position where a primary and a secondary are at maximum coupling, it may be viewed as a two-winding transformer. The remaining windings, if any, are at right angles and do not influence circuit behavior. In analyzing the variations in complex T.R., the factors of importance are seen to be those which affect transformation ratio in any transformer. Temperature increase, for example, increases the d-c resistance of the primary winding causing the phase shift to become more leading. Temperature effects on the lightly loaded secondary are relatively unimportant. The smaller the basic phase shift of the resolver, the less its sensitivity to temperature. Thus large units, or higher frequency units, become relatively insensitive to temperature. On the other hand it becomes very difficult to provide a precise temperature compensation for a size 8 unit, for example, or for a 60 cps size 11 unit.

A somewhat lesser effect occurs as a result of decreased eddy current losses at high temperature. Similar to copper in this respect, the resistivity of the magnet-iron increases with temperature, leading to reduced losses. Phase shift increases in a leading direction adding to the phase lead caused

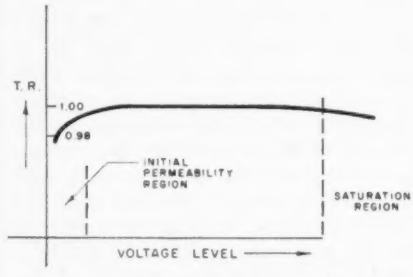

Fig. 10 Variation in transformation ratio with input voltage level. Phase shift follows a similar pattern.

by the primary winding.

Temperature increases cause some reduction in output voltage, particularly in small or low frequency units, but the principal effect is on the phase shift.

Increasing line frequency has just about the opposite effect of increasing temperature. While temperature tends to increase the resistive elements, increasing frequency increases the impedance of the reactive elements. Over the normal operating frequency range, increasing frequency leads to more output voltage and smaller phase shift.

Perhaps the most subtle variations in complex T.R. occur as a result of changes in the input voltage. These occur because of the variation in permeability of the magnetic iron with the input excitation level. As voltage increases, T.R. increases rapidly, due to the rise of initial permeability, reaches a peak and then falls as the iron saturates. When permeability is a maximum, phase shift is minimized. Fig. 10 shows the variation in T.R. with voltage level. Phase-shift variation follows a similar pattern.

These factors affecting complex transformation ratio are readily described quantitatively in terms of the conventional transformer equivalent circuit as explained in a later section.

The last major error category is the misalignment of zero axes of the pairs of primary and secondary windings. This is an extremely difficult error to eliminate. To minimize axis misalignment, maximum uniformity and geometrical perfection is required of the magnetic circuit. Magnetic non-uniformity leads to axis shift with voltage level. Concentricities must be held very closely, particularly in the ever-critical region of the air gap; the magnetic iron must have high permeability, uniformity with freedom from directional properties, high initial permeability to assure good performance at low flux densities, good inter-lamination resistance, and freedom from surface irregularities such as grinding smear. To maintain axis misalignment over a temperature range the rotor and stator

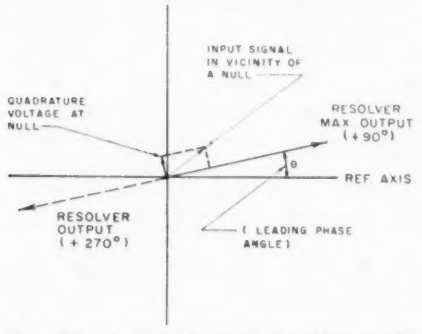

Fig. 11 Vector diagram showing quadrature voltage at null in relation to useful signal voltage.

members must be individually rigid, possess a fixed geometric relationship, and remain undistorted by fits, particularly the changes in housing fit due to differential expansion coefficients, as well as stresses resulting from any encapsulating compounds. The perfection of the unit may in effect be judged by the axis errors over the entire specified temperature range.

While they do not in effect constitute an inaccuracy, null voltages may seriously interfere with getting the most out of a precision resolver in a system application. Null voltage (sometimes called residual voltage) is that voltage which remains when the resolver shaft angle is oriented for a minimum output from a particular secondary winding. The voltage never becomes precisely zero since there are some components which cannot be balanced out merely by repositioning the shaft. These components include a fundamental component, and time harmonics. The fundamental component must of necessity be 90° out of time phase with the signal generated by repositioning the shaft since any "in-phase" components are normally balanced out. For this reason the fundamental component of null voltage is called "quadrature". Fig. 11 shows quadrature voltage in relation to the normal resolver output signal.

Quadrature in an electrical resolver may be generated by a variety of means. Particularly difficult to avoid is quadrature generated by smeared magnetic metal on the air-gap surfaces of the resolver. This smeared metal constitutes a short-circuit between laminations, and short circuit currents flow much as in the shading coil of single-phase shaded pole induction motors. As in shaded pole motors, rotating fields are effectively set up which cannot be balanced out for any position of the rotor shaft.

Quadrature is minimized by using a good quality low-loss magnetic material in a geometrically accurate magnetic circuit with uniform interlamination resistance, and a surface free from imperfections, particularly grinding smear. Sometimes laminations are used in which the finished wound stacks require no grinding, but here any improvement in quadrature is usually nullified by a loss in accuracy due to the lesser dimensional accuracy of the unground members.

The second component of null voltage is the time harmonic voltage. This is a higher frequency voltage caused by nonlinearity of the iron portion of magnetic circuit. Time harmonics are emphasized when permeability is low, when the magnetic circuit is not perfectly uniform in all directions and when saturation sets in. Unfortunately

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Environmental Capabilities
Vibration:
5 g, 20-1000 cps;
10 g, 1000-2000 cps
Temperature Range (operative):
—54°C to +71°C
(non-operative):
—65°C to +85°C
Altitude: Unlimited

Pickoffs
Excitation:
26V, 400 cps, single phase
Error from E.Z.: 10 min. max.
Output Voltage (line to line):
11.8V ± 5% max.

Motor
Excitation:
115V, 400 cps, three phase
Power: Starting: 35 watts
Running: 7.5 watts

Performance Characteristics
Repeatability of Established Vertical:
To within a cone of half angle equal to 12 minutes of arc
Scorsby Drift Rate in 5 Min. Time:
0.3°/min. (average)
Erection Rate:
Normal: Between 2° and 4°/min.
Fast: 80°/min. intermittent,
40°/min. continuous

Physical Features
Anisoelastic Drift:
0.08°/min/g² at resonance
Weight: 5.5 lbs. (approx.)
Mass Unbalance: 0.1°/min/g

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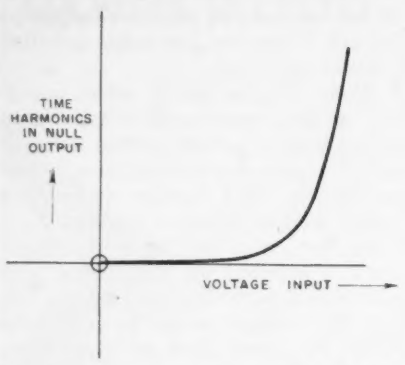

Fig. 12 Variations in harmonic null output component with input signal level.

the highest permeability magnetic materials have low saturation densities. On the positive side, however, resolvers are generally low flux density units, unlike some synchros. Fig. 12 shows null harmonic voltage as a function of resolver input voltage (proportional to flux density). Well designed units operate below the knee of the saturation curve.

Fig. 13 shows the permeability characteristics of common magnetic materials for resolvers. Where optimum performance at low flux densities is required, alloys containing 80% nickel are best. These have a high initial permeability which is necessary for good performance at very low flux densities.

MANUFACTURING ERRORS

The angular inaccuracies and the T.R. and phase shift errors described above are characteristics inherent in a particular design and appear uniformly in all production units. There are, in addition, manufacturing inaccuracies which introduce errors. Eccentricity of rotor and stator axes, and out-of-roundness of the stator are the principal geometric errors resulting from manufacturing inaccuracies. These machining errors lead to random angular inaccuracy as well as misalignments in the axes of the units. They are in addition to the null voltages described above. Very often resolvers are selectively classified after their performances have

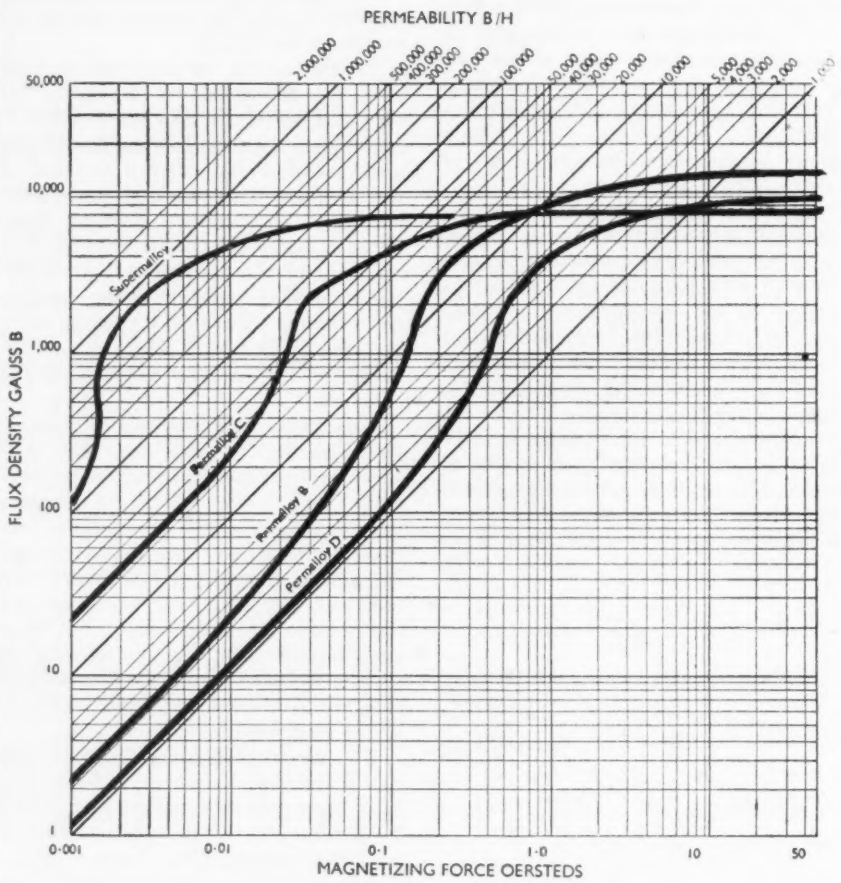

Fig. 13 Permeability characteristics of magnetic steels commonly used in electrical resolvers. From "The Magnetic Properties of the Nickel-Iron Alloys", the Mond Nickel Company Limited.

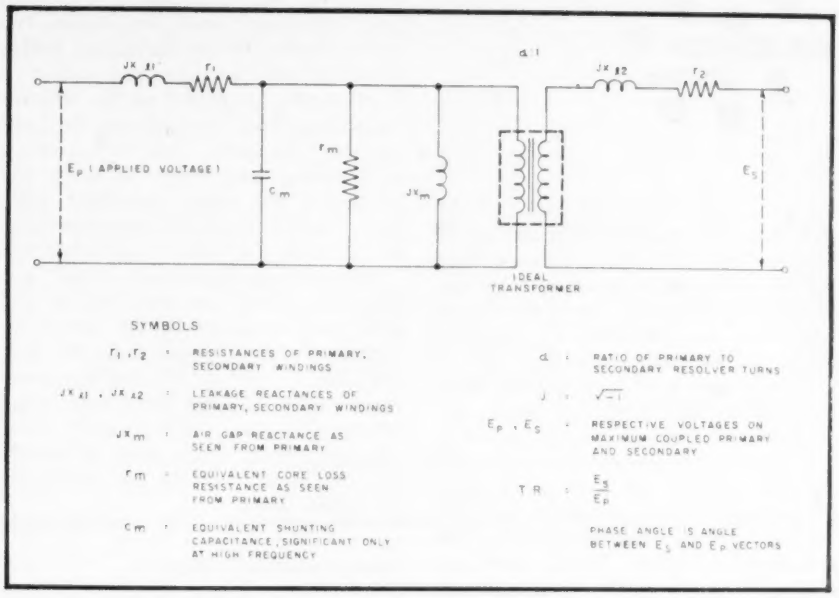
a:1
$jX_{\ell 1}$
r_1
$jX_{\ell 2}$
r_2
E_p (APPLIED VOLTAGE)
r_m
C_m
jX_m
E_s
IDEAL TRANSFORMER
SYMBOLS
r_1, r_2 : RESISTANCES OF PRIMARY, SECONDARY WINDINGS
$jX_{\ell 1}, jX_{\ell 2}$: LEAKAGE REACTANCES OF PRIMARY, SECONDARY WINDINGS
jX_m : AIR GAP REACTANCE AS SEEN FROM PRIMARY
r_m : EQUIVALENT CORE LOSS RESISTANCE AS SEEN FROM PRIMARY
C_m : EQUIVALENT SHUNTING CAPACITANCE, SIGNIFICANT ONLY AT HIGH FREQUENCY
a : RATIO OF PRIMARY TO SECONDARY RESOLVER TURNS
j : $\sqrt{-1}$
E_p, E_s : RESPECTIVE VOLTAGES ON MAXIMUM COUPLED PRIMARY AND SECONDARY
T.R. : $\frac{E_s}{E_p}$
PHASE ANGLE IS ANGLE BETWEEN E_s AND E_p VECTORS

Fig. 14 Transformer-type equivalent circuit of electrical resolver.

been measured. Depending upon the observed misalignment in axes, resolvers may be designated as one or two input and/or one or two output units. This breakdown is often a necessary economic move since the tolerances involved in reducing axis errors to a negligible value are impractical in production. In specific applications there is no loss in accuracy since only the necessary number of carefully tested windings are used. Sometimes trimming is employed, based upon use of special windings connected in as part of the final test of the resolver. These windings may be used to match up two secondary windings or to correct axis errors.

APPLICATION FACTORS

Resolvers are available in the same range of frame sizes commonly used for servomotors. However, because of accuracy requirements they are more common in the larger sizes such as in the size 23 (2¼" dia.). The synchro-mount front end has similarly become almost standard. Housings of anodized aluminum are replaced by stainless steel in the more accurate models where a highly rigid housing plus a thermal expansion coefficient matching the magnetic lamination stack are essential to the achievement of stable performance. Shaft run-out, mounting tolerances and radial play must be commensurate in accuracy to the overall performance requirement. Actually a fraction of a minute is all the error that can be permitted as a result of the mechanical positioning error due to the accumulation of dimensional and servomechanism tolerances. Overall resolver

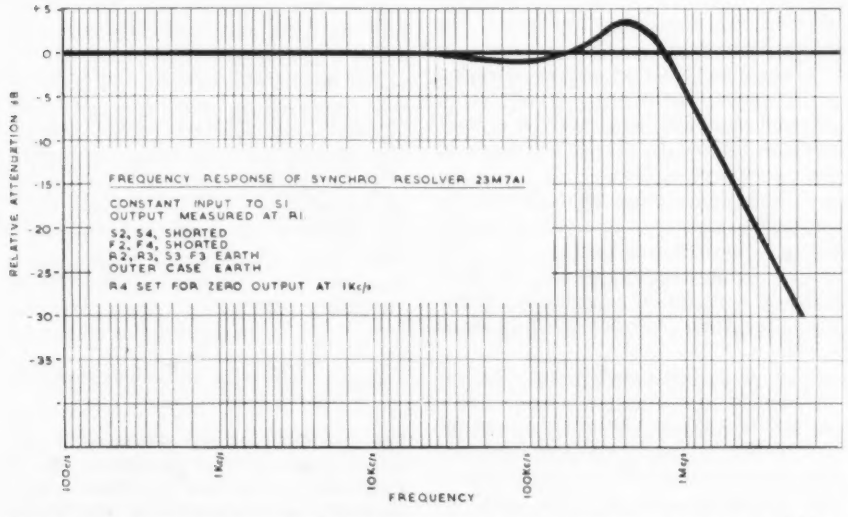

Fig. 15 Variation of transformation ratio over a wide frequency range of a Muirhead resolver.

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5g, 20-1000 cps; 10g, 1000-2000 cps
Temperature Range (operative):
—54°C to +71°C
(non-operative):
—65°C to +85°C
Altitude: Unlimited

Azimuth Pickoff
Excitation:
26V, 400 cps, single phase
Output (sinusoidal):
11.8V ± 5% max.
Error from E.Z.: 10 min. max.

Motor
Excitation:
115V, 400 cps, three phase
Speed: 23,500 RPM
Power: Starting: 35 watts
Running: 7.5 watts

Performance Characteristics
Drift: 4°/hr. max.
Leveling Rate:
Between 2° and 4°/min.
Azimuth Torquing Rate:
360°/min. (intermittent)
40°/min. (continuous)

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COMPONENTS DIGEST

accuracy may be of the order of 2-3 minutes. The gearing which drives the resolvers must also reflect this accuracy. Spring-loaded gears are frequently employed to eliminate backlash. Large gears are also essential for accurate angle transmission, but the size is usually limited by system requirements, particularly the need for quick disassembly of components for servicing.

Where space permits, resolvers with terminal boards are most convenient. Many terminals are normally required for the compensating windings (which are described later). Leads, while not as easy to use, are often most practical in the miniature units.

THE EQUIVALENT CIRCUIT

As explained above, the resolver may be considered as a conventional transformer when an input winding and an output winding are oriented for maximum coupling. The standard transformer equivalent circuit, Fig. 14, may be used in making a mathematical analysis of behaviour. The equivalent circuit relates the significant parameters of the electrical resolver to specific circuit elements so that variations in performance may be described in terms of these elements. For example.

(a) Variations in d-c resistance with temperature occurs as changes in r_1 and r_2.

(b) Variations with frequency show up as corresponding changes in the impedances of reactive elements.

(c) Changes with line voltage are described by changes in X_m, the impedance value of which is markedly affected by the permeability of the magnetic material.

Thus, the principal factors affecting performance, including the effects of external electrical loads may be numerically evaluated by direct reference to the equivalent circuit.

Although somewhat approximate, the equivalent circuit is particularly useful in analyzing resolver performance over a wide frequency range. Fig. 15 illustrates the variation in complex transformation ratio over a wide frequency range.

The equivalent circuit may be experimentally measured where desirable by the techniques described in standard textbooks for the measurement of the equivalent circuit of transformers and induction motors. The standard test procedures include measurements of open-circuit and short-circuit impedances. The accuracy is extremely good in larger units, or higher frequency units. Where the unit is readily disassembled, leakage impedance is conveniently measured as the winding impedance with the opposing magnetic member removed. This measurement technique is surprisingly accurate, but of course not always practical. Null-type bridge circuits are recommended for accurate impedance measurements.

Approximate equivalent circuit calculations which are very simple and give fairly accurate results ignore resistive elements when making T.R. calculations, and ignore leakage reactances when making phase-shift calculations. As may be expected, these approximations apply most accurately to components having an inherently low phase shift.

COMPENSATION CIRCUITS

Because they have a relatively high output impedance, a low input impedance, plus the complex T.R. errors described above, electrical resolvers require means for compensating for their individual errors, as well as the errors they incur due to their interaction (loading) when connected together in a system. Booster amplifiers providing excitation for each input admirably perform the functions of isolation, standardization (adjustment of a precise T.R. and phase shift) and compensation (for variations in line voltage, frequency, and temperature). These amplifiers are frequently packaged in pairs to provide excitation to two inputs of a resolver. Whereas in the past booster amplifiers had commonly been designed around vacuum tubes, as might be expected, they are now primarily transistorized. The size reduction brought about by transistor-

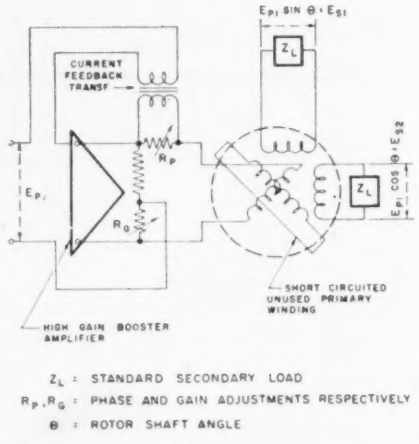


Fig. 16 Network compensation of electrical resolver. The resistance, R_P, is frequently connected in series with a carefully selected inductor which simulates the resolver primary leakage reactance.

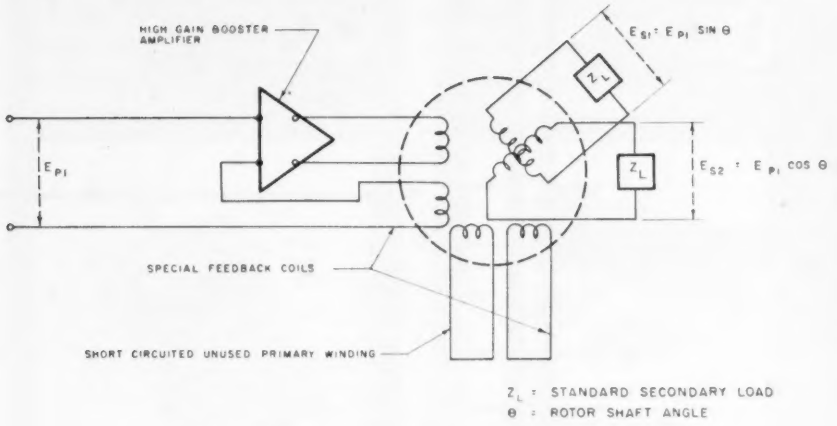


Fig. 17 Winding compensation of electrical resolver.

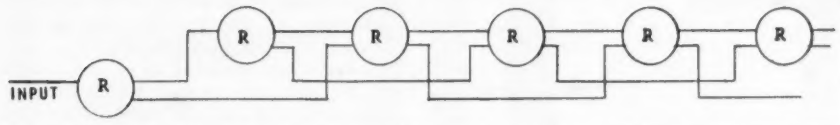


Fig. 18 (a) Basic schematic of a resolver chain used in a typical coordinate converter system. The diagram shows the idealized interconnection of resolvers to provide the required computation function.

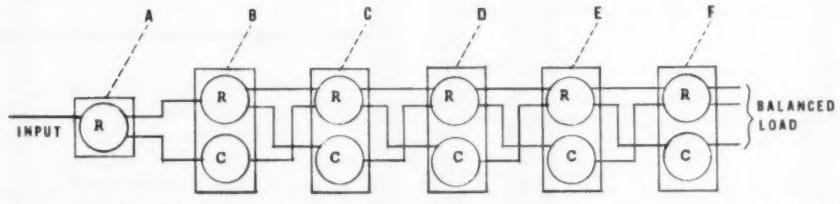


Fig. 18 (b) Resolver chain making use of compensators. These compensators behave like resolvers locked in the maximum coupling position. Thus, when voltages are combined at successive levels in the chain, the individual resolvers see uniform input and output impedances and a common voltage and phase reference where two inputs are excited. This type circuit makes for considerable circuit simplification over booster-compensated arrangements.

Courtesy of Kearfott Div., General Precision, Inc.

ization has made it possible to couple miniature low heat amplifiers directly on the back of the resolvers. This is not only particularly convenient for application, but also greatly simplifies system wiring. The big disadvantages of transistor units are the limited high temperature extreme and high cost.

Before considering just how booster amplifiers are used in resolver circuitry, it is important to note their stability requirements. For the most accurate resolvers, booster gain must be stable to approximately 0.01% with phase shift of a fraction of a minute. Typically, a basic gain of 10,000 is reduced to slightly greater than unity by about 100% negative feedback. The design of the feedback circuit is particularly critical in such a high gain amplifier if oscillations are to be avoided.

Fig. 16 shows a *network-compensated* circuit which is widely applied. Here current feedback is used to compensate for the drop across the primary leakage impedance of the resolver. A network simulating the primary leakage impedance is inserted in series with the primary. The voltage across it, proportional to the primary leakage drop, is fed back to the amplifier input to provide the necessary compensation. The compensation is suitable over a temperature and frequency range.

The net effect of the current feedback is to effectively place the booster input voltage across the air-gap impedance of the resolver. Thus, changes in air-gap reactance due to permeability change, for example, do not change the T.R. or phase-shift.

Standardization is accomplished by adjusting amplifier gain so that the overall (resolver plus booster) T.R. equals precisely unity in a typical case.

BASIC BUILDING BLOCKS FROM KEARFOTT

FREE GYRO

A highly reliable, two-degree-of-freedom instrument utilizing AC synchro transmitters at each gimbal axis. Designed to operate under the most severe missile conditions, this gyro has AC torquers mounted at each gimbal axis to permit command positioning or slaving of spin axis to desired reference position; each torquer capable of producing a precession rate of 360°/minute with 12.5 watts/phase power input.

TYPICAL CHARACTERISTICS #Q2315

Environmental Capabilities
Temperature Range:
(operative): —54°C to +71°C
(non-operative): —65°C to +85°C
Altitude: Unlimited
Vibration: 10g, 10-2000cps

Pickoffs
Excitation:
26V, 400 cps, single phase
Output (sinusoidal):
11.8V ± 5% max.
Error from E.Z.: 10 min. max.

Motor
Excitation:
115V, 400 cps, three phase
Speed: 23,500 RPM
Momentum:
2.25 x 10^6 gm cm^2/sec

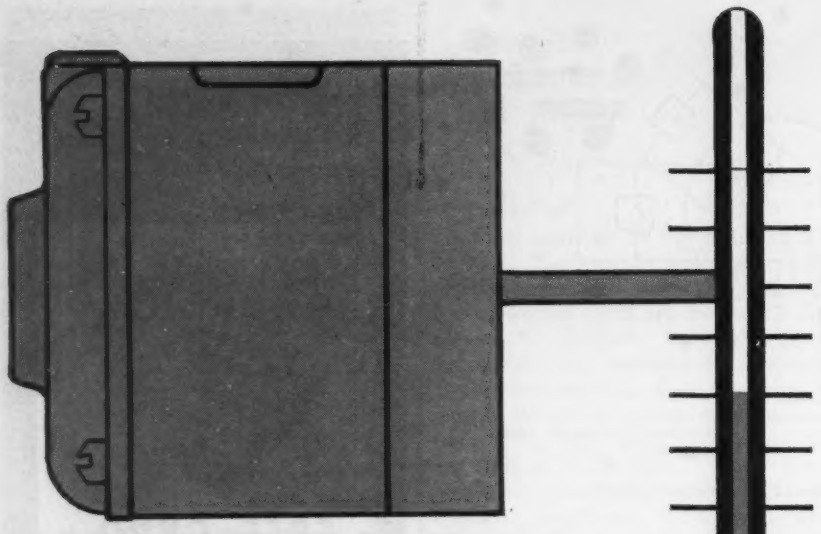
Caging and Preset Provision
(Electrically energized torquer type)
Excitation: 115V max./phase
Torquer Constant:
22.8 dyne cm/Volt²

Performance Characteristics
Free Drift:
5°/minute each axis
Runup Time:
1 minute max.
Torquing Rate:
360°/min. (intermittent)
40°/min. (continuous)

Write for complete data.

KEARFOTT DIVISION
GENERAL PRECISION INC.
LITTLE FALLS, NEW JERSEY

CIRCLE NO. 69 ON INQUIRY CARD



Holtzer-Cabot Solves Fractional H.P. Motor Problems

12 MONTHS CONTINUOUS OPERATION at ambients up to 176° F.

A leading instrument manufacturer*, had the problem of continual motor failures after 2 to 3 months service in an instrument which required a minimum of one year's continuous duty in maintained ambients up to 80° C. (176° F.)

The thermostated, infra-red instrument in which the motor was to be used, required a 24-hour stabilizing period, dictating that no maintenance be performed.

To solve this problem, engineers from both the instrument company and from Holtzer-Cabot cooperated in the development of a motor with increased radiation area, plus reduced power input. This resulted in a motor temperature rise of only 20° C. as compared with 35° C. in the motors formerly used.

To provide positive lubrication, grease reservoirs were provided outside the bearing and a long-life stable grease suitable for high temperature was selected.

The result was a motor which has now been in successful operation for over 12 months without any motor failure or trace of bearing wear.

* Name on request

Write for Information! Holtzer-Cabot specializes in the design and manufacture of fractional horsepower motors for all types of applications. For complete details on Holtzer-Cabot motors for specific applications, and a copy of "Key Factors in Selecting AC Motors for Instrument Service" write direct or use Readers Service Card.

HOLTZER-CABOT
MOTOR DIVISION
National Pneumatic Co., Inc., Boston 19, Mass.

CIRCLE NO. 53 ON INQUIRY CARD

COMPONENTS DIGEST

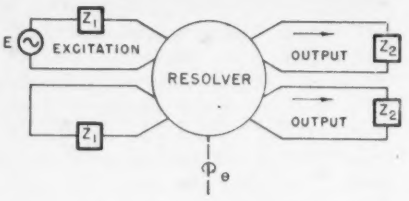


Fig. 19 Booster'ess resolver employing iterative terminations. The equivalent transformer circuit of the resolver, plus the constancy of input and output impedances such as the termination of windings in the iterative impedances, Z_1 and Z_2. Thus, regardless of how many resolvers are cascaded in chains such as in Fig. 18, the input and output impedances will *always* correspond to Z_2 and Z_1, respectively. Attributable to *each* resolver will be an attentuation factor and a phase shift so that voltage level at any point in the circuit is defined.

The current feedback resistor is selected to provide an exact zero phase-shift for the resolver plus booster combination. The resistors which set T.R. and phase shift are wired directly into the resolver so that resolvers or boosters may be interchanged with no loss in accuracy. That is, all selected circuit elements are included in the resolver itself.

Fig. 17 shows how winding *compensation* works. Here a special compensating winding is wound in good magnetic coupling with the primary. The voltage induced in the compensating winding is a measure of the air-gap magnetic flux. Feeding this voltage back and comparing it with the input signal, in a high gain loop, effectively holds the flux in the resolver air-gap in a precise relationship to the input signal. This provides the necessary compensation. Winding compensation is especially accurate over a wide range of operating conditions where network compensation accuracy may begin to fall off.

NON-BOOSTER RESOLVER COMPENSATION

Where maximum system compactness is required resolvers may be used without booster amplifiers in a variety of schemes. The simplest but most limited circuit application occurs where the resolver is excited directly from the line or other low impedance source,

BASIC BUILDING BLOCKS FROM KEARFOTT

SIZE 11 SYNCHRONOUS MOTOR

Featuring pull out torque efficiency of 50% nominal with 3.4 watts input and 3 watts pull out power, this synchronous motor represents a major achievement in terms of performance for a unit of this extremely small size. Additional advantages made possible by Kearfott's unique design include resistance to environmental extremes, light weight construction and low unit cost. This motor and its variations are available in production quantities.

TYPICAL CHARACTERISTICS R172

Excitation:	Phase 1	Phase 2
Voltage	40V	40V
Frequency	400 CPS	400 CPS
Power	2.3 Watts	2.3 Watts
Current	0.157 Amps	0.157 Amps

Performance:

Synchronous Speed	8000 RPM
Stall Torque	0.2 In. Oz.
Pull Out Torque	0.35 In. Oz.
Pull In Torque	0.15 In. Oz.

Write for complete data.

BASIC BUILDING BLOCKS FROM KEARFOTT

FERRITES

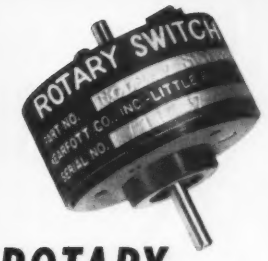
Kearfott's Solid State Physics Laboratory formulates, fires and machines permanent magnet ferrite materials of various compositions. Typical high-efficiency array utilizes Kearfott PM-3 ferrite material with specially designed pole pieces to produce a design both smaller and lighter than other arrays of equivalent magnetic field strength. Because magnets may be custom engineered to specific requirements, user is not restricted to stock magnet types, thereby providing greater latitude in parameters for focusing arrays. Pole pieces may also be provided according to specification, with the added assurance that, because of special Kearfott design techniques, B axial magnetic fields approximately 10% higher than those generally obtained in standard types may be produced.

TYPICAL CHARACTERISTICS

Peak Magnetic Field Strength	1200 gauss
Period	0.560 in.
Length	5.64 in.
Inside Diameter of Pole Pieces	0.400 in.
Outside Diameter	2.0 in.
Weight	3.2 pounds

Write for complete data.

BASIC BUILDING BLOCKS FROM KEARFOTT



ROTARY SWITCH

Kearfott's rotary switching devices for missile and aircraft systems are used to sequence or switch circuitry as a function of time or shaft position. Used in conjunction with sensitive relays or solid state switching techniques, high current loads can be handled. These switches consist primarily of shaft assembly and bearing mounted cylinder divided into conducting and non-conducting segments with continuous track for common input. Multiple conductor "broom" type brushes ride on each cylinder track while number of tracks and segmentation of each is function of the number of circuits and type of "on-off" sequencing required.

TYPICAL CHARACTERISTICS P1280-11A

Number of switching tracks: 2

Angular Segmentation (both referenced to 0° start):
Track 1 — Non-conducting about 0° + 50°
Track 2—Conducting 0° -180°
Non-conducting 180° -0°

Mechanical Accuracy of Segmentation:
±1° (better as required)

Starting and Running Torque:
0.1 oz.-in.

Current Capacity:
50 ma at 28V/Brush (suitable for any sensitive relay or solid state switching circuits)

Write for complete data.

Free Gyro

Vertical Gyro

Directional Gyro

Engineers: Kearfott offers challenging opportunities in advanced component and system development.

KEARFOTT DIVISION
GENERAL PRECISION INC.
LITTLE FALLS, NEW JERSEY

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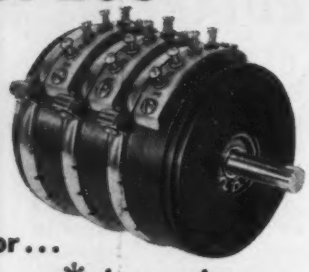
South Central Office: 6211 Denton Drive, Dallas, Texas
West Coast Office: 253 N. Vinedo Avenue, Pasadena, Calif.

ON MOTORS
CIRCLE NO. 54 ON INQUIRY CARD

ON FERRITES
CIRCLE NO. 55 ON INQUIRY CARD

ON SWITCHES
CIRCLE NO. 56 ON INQUIRY CARD

PRODUCTION POTS WITH CUSTOM SPECS*



for...

* sine-cosine
* secant
* square law
* empirical functions

Designed for exacting requirements in analog computations, Micro-Lectric's Series C-550 servo mount potentiometers provide exceptional conformity to specified mathematical functions —eliminate the need for cams, padding, or other shaping devices.

Single units, or stacked assemblies, in a wide range of resistance values to meet your specific needs.

Typical Sine-Cosine Characteristics

size	2 inches
resistance range	200 ohms to 70K per quadrant
conformity	0.25% peak to peak
temperature range	—55° to +85° C.
noise	less than 100 ohms
starting torque	0.6 oz. in. max.
running torque	0.35 oz. in.
life	1,000,000 rev.

When the job calls for custom performance **plus** prompt availability, it will pay you to contact Micro-Lectric. Write today for complete data in Bulletin 550-1.

MICRO® LECTRIC

Division of Micro Machine Works
Roosevelt, L. I., New York

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COMPONENTS DIGEST

such as a transformer or inductive potentiometer. Here the primary may be temperature compensated by means of thermistor circuits. The phase-shift could even be brought to zero, by R-C circuits on the output, for example. This type application provides no frequency compensation (without complex equalizing circuits) or compensation for variations in line voltage. Line excited resolvers may be balanced against other line excited devices such as potentiometers, if suitable phase-shifting and voltage scaling is provided.

Much more flexible is the general technique for using boosterless resolvers in chains such as is often necessary in the solution of complex trigonometry problems, particularly in connection with spherical triangles. The techniques for doing this are illustrated by the examples of Figs. 18 and 19. Here the resolver voltages are successively attenuated by each resolver in the chain. Nevertheless if account is taken of this attenuation in combining voltages, an accurate trigonometric solution may be reached. This type circuit is fundamentally not as accurate as a chain of booster-compensated units but the economy, simplicity and reliability derived from the elimination of booster amplifiers is striking. Among the disadvantages are the loss in voltage in successive stages of the chain, meaning more residual voltage and less signal at the servo null points, and the need for accuracy in the input and output impedances of the resolvers, parameters which are not normally held to close tolerances.

These boosterless resolver chains are particularly insensitive to temperature changes, provided the whole system temperature is uniform. Frequency variations likewise are relatively unimportant, the same system being operable at both 60 cps and 400 cps in a

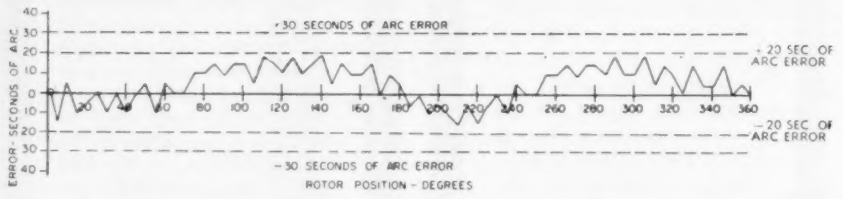


Fig. 20 Typical error curve, size 25 resolver used as two-phase four-wire synchro.

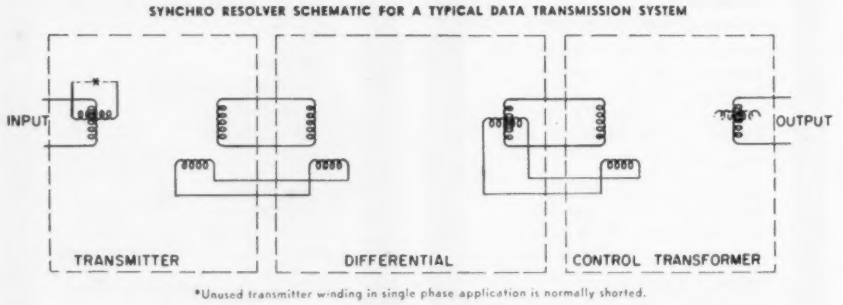


Fig. 21 Resolvers substituting for synchros in high accuracy angle transmission system. The need for high accuracy synchros has become increasingly important as the standards of accuracy for computers, automatic control, and data transmission systems become more critical. To satisfy the demand for such components, Kearfott has developed these Size 25 units whose maximum error from electrical zero does not exceed one-third minute (20 seconds). In addition to the high accuracy inherent in these components, they have the advantage of high versatility, since the same basic design permits their function as four-wire control transmitters, control differential transmitters, and control transformers. In a typical data transmission system, a string of three such components are coupled together to perform a desired function, with a total system error that is less than 36 seconds. Using 30-second resolvers, total system error is less than 60 seconds.

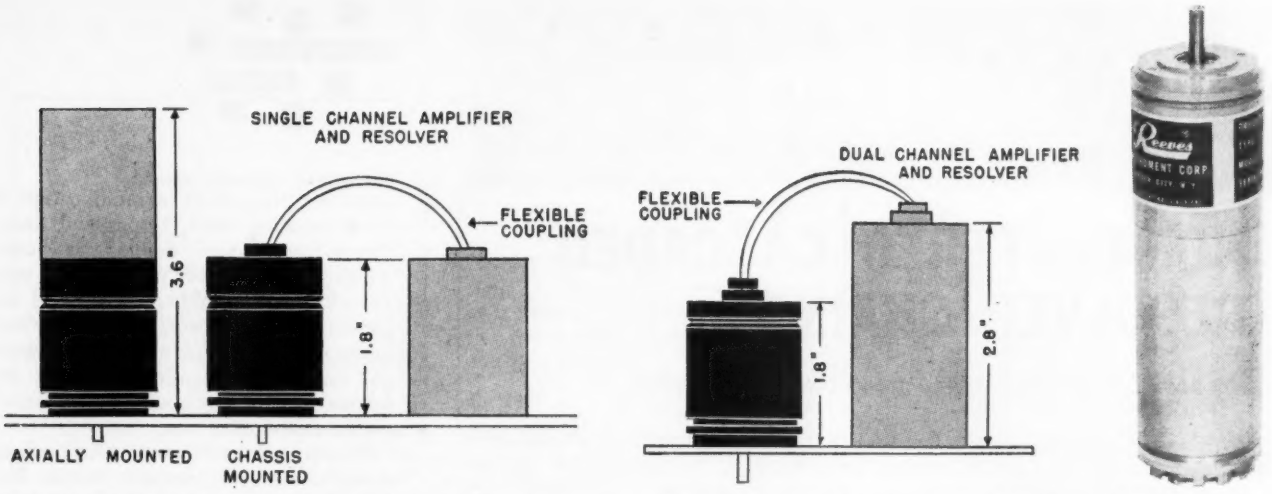


Fig. 22 Mechanical configurations of resolver-booster combinations, single channel, and dual channel. The single channel booster may be axially mounted directly on the resolver. The outline drawings are Kearfott units; the photograph shows a Reeves unit.

typical instance. Where reduced accuracy is permissible, these chains have much to recommend them.

RESISTANCE-TYPE RESOLVERS

Resistance type resolvers lack the flexibility of the induction resolver with its two input and two output windings. A pair of two output resistance potentiometers can provide an equivalent function when they are suitably coupled with their shafts in a corresponding zero position. There is a problem of isolating input circuits and providing suitable grounds when d-c excitation is used. In a-c applications transformers may be required which are obviously unnecessary in the case of the a-c induction resolver. Output impedance of these resolvers depends upon shaft position which means that loading will introduce angular inaccuracy. Where the load is known however, it may be possible to intentionally include a nonlinearity to compensate for loading errors. As with any wire-wound nonlinear potentiometers, resolution problems are considerably more severe than for linear devices.

On the positive side however, sinusodial resistance potentiometers do not require temperature, frequency, or voltage compensation and where boosters are used, they need provide only isolation. The applicability to d-c systems is probably their strongest virtue, since here a-c resolvers are totally out of the question. The absence of residual voltages which occur in induction resolvers is a marked advantage. On the other hand they do exhibit wiper noise, and at high frequencies, phase shifts resulting from wiring capacitance. In the design of sine-cosine potentiometer circuits considerable ingenuity is necessary to minimize loading effects, the need for isolation transformers, and to provide convenient scaling and zeroing adjustments.

COMMERCIALLY AVAILABLE VARIETIES OF SINE-COSINE GENERATORS

While the preceding sections provide the general back-ground for the evaluation and selection of since-cosine devices, the information can be conveniently supplemented by brief descriptions of some specific devices.

Kearfott Division, General Precision Inc. has developed a number of interesting types. Fig. 20 shows the error pattern of an extremely high accuracy size 25 resolver (dia. approx. 2.5″) used as a four wire synchro with a typical maximum error of 20 seconds. Fig. 21 shows a typical "synchro" chain using these resolvers. Essentially this unit makes the most of the design possibilities described above, with maximum advantage being taken of the relatively large size. The larger unit has more slots, which permits a more precise approximation to the desired sinusoidal function.

Fig. 22 shows some of the booster-resolver mechanical configurations. The figure is self explanatory.

Radio frequency resolvers have been developed for uses such as R. F. direction finders and the resolution of radar receiver data, see Table IV. Resolvers for such applications should have the widest possible band-width to transmit the full range of frequencies without

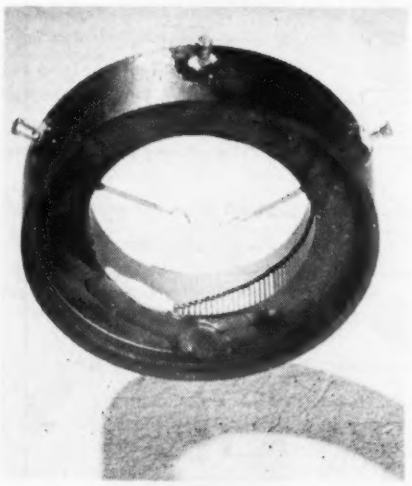


Fig. 23 Resistance element of a C. I. C. carbon-film sinusoidal potentiometer.

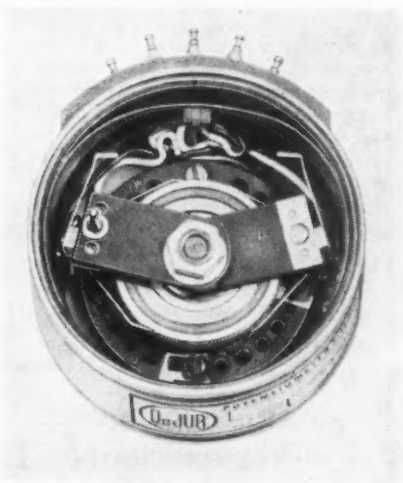


Fig. 24 Sine-cosine potentiometer, where resistance element card is shaped to provide desired sinusoidal function.

ENGINEERING
REPORT
ON BENDIX COMPONENTS

NON-BUFFERED CASCADED RESOLVER CHAINS

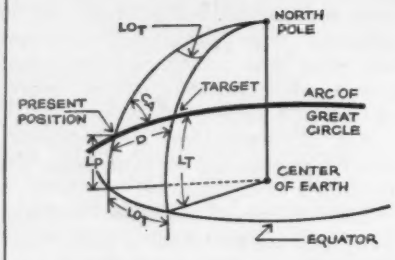
FOR NAVIGATIONAL, GUIDANCE, AND FIRE CONTROL COMPUTERS

Newly-developed techniques enable Eclipse-Pioneer to solve coordinate transformation problems using size 10 (or smaller) resolvers with performance exceeding resolver chains using size 23 resolver and feedback buffer amplifiers.

Our design philosophy is based on the premise that all component parameters will be allowed to fluctuate with variations in excitation voltage, frequency, and ambient conditions. All resultant signal variations can be closely predicted through digital computer analysis.

As a result of Eclipse-Pioneer's experience in utilizing resolver chains in its navigational systems, considerable data has been compiled which may be helpful in solving your problems. Write us today for complete information.

TYPICAL PROBLEM



PROBLEM: Design a computer to provide an aircraft with continuous bearing and range information along the arc of a great circle.

C_A—Bearing

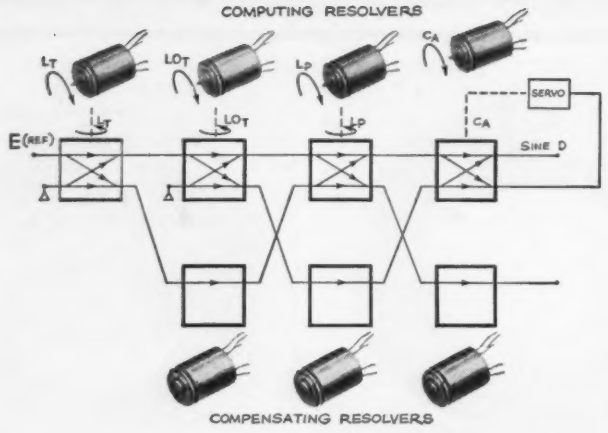
LO_T—△Longitude measured from present position to target

L_P—Latitude of present position

L_T—Latitude of target

D—Great Circle distance from present position to target.

SOLUTION



Eclipse-Pioneer Division
Teterboro, N. J.

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CIRCLE NO. 46 ON INQUIRY CARD

COMPONENTS D'GEST

excessive phase-shift or modification of transformation ratio. Upper and lower "break-frequencies" define the bandwidth of the resolver much as for conventional transformers. Distributed capacitances, core losses, and skin-effect in the copper conductors are the principal design factors affecting R. F. resolvers as contrasted with conventional resolver design factors.

Computer Instruments Corporation, manufacturers of precision carbon film potentiometers, manufacture precision sinusoidal potentiometers of exceptional accuracy and essentially infinite resolution. They rely on a technique of "trimming" the carbon film by mechanical means at closely spaced angular intervals to secure claimed accuracies to 0.015%. Features claimed for the C.I.C. sonusoidal potentiometer include high resolution, compensation for loading, frequency from d-c to video range, and the usual reliability features characteristic of this type of potentiometer. Fig. 23 shows the resistance element of a C.I.C. sinusoidal potentiometer with the calibration marks generated by their semi-automatic trim technique.

Fig. 24 shows a somewhat more conventional construction by DeJur-Amsco. These units deliver 2 separate voltage outputs with peak-to-peak accuracies to ±0.25% on special order.

Waters Mfg., Inc. provides a miniature (1⅛" dia.) two output sine-cosine potentiometer with a ±1% peak-to-peak terminal conformity.

Fairchild Controls Corp. manufactures a 1-1⅛" potentiometer model designed for high accuracy in a small package. It is a peripheral card design embodying extremely tight concentricity and radial alignment. Functional conformance of ±0.5%, peak-to-peak, have been obtained on production quantities, and as a phase shifter, the standard production tolerance is ±0.7°. This design also has the capability of containing as many as four internal resistors to provide either portions of sine functions or balancing legs when the sine-cosine pot is used as a resolver or phase shifter to replace the conventional flat card design which is usually much larger in diameter.

Fairchild also offers a 1⅞" design used almost exclusively for resolving and phase shifting purposes. The flat card design permits accuracies of ±0.7° as a standard tolerance.

Their 2" type 754 model has been exclusively designed for exceptionally

Definitions Related to Electrical Resolvers

Type Designation

Ordnance classification makes use of coding to identify resolver parameters:

23/(a) R/(b) 32/(c)
N/(d) 4/(e) d/(f)

(a) The O.D. to the nearest highest tenth-inch (as in synchros).
(b) R designates that unit is resolver.
(c) These digits indicate nominal input impedance in hundreds of ohms (to the nearest hundred on the high side if impedance is not exact multiple of hundreds).
(d) Compensation is indicated by the letter following impedance:

Type	*Letter Code*
Resistor compensated	R
Winding compensated	W
Resistor and winding compensated	B
Not compensated	N

(e) Excitation frequency is next code number:

f cps	Code
60	6
400	4

(f) The last letter, if present, indicates a modification which differs slightly, either mechanically or electrically, from the basic design.

Resolver Characteristics

A resolver is basically a transformer whose coupling between primary and secondary can be varied. The function of a resolver is to produce secondary voltages which are sine or cosine functions of the input signals, depending on the angular position of the rotor relative to the stator. An ideal resolver will have primary and secondary windings exactly in quadrature with each other at exact electrical zero.

Windings

A simple resolver has two separate stator and two separate rotor windings, one winding of each pair in space quadrature to the other. In both cases, significance of this layout is that an input to one stator winding will develop one rotor voltage which is related to the sine of the angle between the stator and rotor shaft, and the second rotor voltage will be related to the cosine of this same angle. Applying inputs to both stator windings delivers rotor outputs which are sums or differences of the trigonometric components of the two input signals. Where close control of TR, phase shift and loading is required over wide temperature and/or frequency ranges, compensating windings are inserted in juxaposition to the stator windings.

Excitation

The example above used the stator as the excited windings; in practice the stator or rotor can be energized. The energized winding is called the primary and the output winding is called the secondary.

Phase Shift

Electrical angle by which the output voltage differs from the input excitation voltage in time phase.

Phase Shift Variation

Change of phase shift from its nominal value.

Rotor Interaxis Error

Deviation from 90° perpendicularity of rotor windings expressed in mechanical degrees as checked with one stator excited.

Stator Interaxis Error

Deviation from 90° perpendicularity of stator windings expressed in mechanical degrees. Normally only the rotor inter-axis error is specified in the catalog sheets since the stator error can be corrected with external circuitry.

Total Null Voltage

Output voltage present at a position of minimum coupling with respect to an excited input winding and with the other input winding short circuited—all other windings being open circuited.

Transformation Ratio

(T.R.)—A ratio of the direct-time-axis (in-phase) component of the output voltage taken with respect to the input voltage at maximum coupling.

Upper Frequency Limit

Frequency at which the T.R. begins to rise towards the peaking frequency.

Useful Carrier Frequency Range

Frequency range over which the T.R. is constant within specified limits and the output is sinusoidally proportional to the angle of shaft rotation.

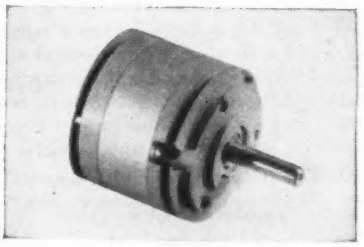
Zero Reference Angle Or Electrical Zero

The angle where the fundamental in-phase voltage is zero. Alternately, this is the point where $\theta = 0$ in the defining equations. This zero angle is denoted roughly by suitable shaft and external case markings.

ENGINEERING REPORT ON OTHER BENDIX COMPONENT PACKAGES

GEAR HEADS

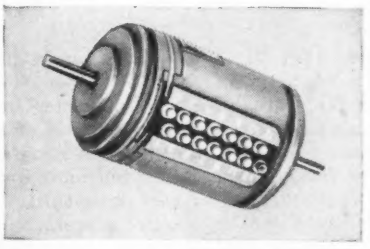
Compact units that provide output motor speed reductions.



These easily detachable heads are available in various frame sizes, and supply reductions in ratios ranging from 7.22:1 to 42,471.90:1. Ball bearings are Class A. B. E. C. 5, or better, and gears are cut to AGMA Precision II tolerances, or better, with backlash held to 30 minutes, or better. Adaptable to variety of motors and motor generators. Write for details.

CODED COMMUTATORS

Shaft position-to-digital converters in miniature.



For use with digital control systems, data processing equipment, or computers, these small devices convert analog information to binary digital form. Size particularly suits them to airborne applications. Unit shown consists of 7-digit converter utilizing linear, doublebrush, natural binary code. Each track brush is split for better contact. Unambiguous output giving shaft resolution to 1 part in 128 can be provided. Ask for details on the many models available.

Manufacturers of
GYROS • ROTATING COMPONENTS
RADAR DEVICES • INSTRUMENTATION
PACKAGED COMPONENTS

Eclipse-Pioneer Division

Bendix AVIATION CORPORATION

Teterboro, N. J.

CIRCLE NO. 47 ON INQUIRY CARD

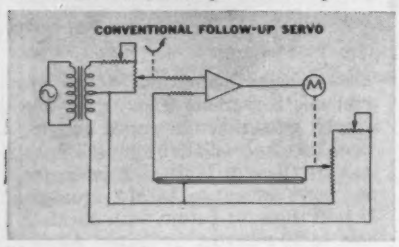
DESIGN IDEAS FOR ELECTRONIC ENGINEERS:

How to improve servo performance with Vernistat* a. c. potentiometers

Typical example shows how they increase servo reliability and accuracy, reduce system complexity and cost

Servos which utilize resistance potentiometers must also include several other components to achieve high accuracy. In addition, these components may increase cost, create added problems in design, and add an element of unreliability.

FOR EXAMPLE, a simple follow-up servo:



Here, to position a remote shaft in accordance with the position of the input shaft, resistance potentiometers and summing resistor networks are used. This requires an accurate center-tapped voltage source, so that the two potentiometers will be excited by equal voltages of opposite phase. When the shafts of the two potentiometers correspond, the input to the amplifier will be zero.

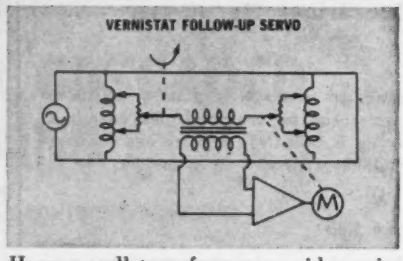
THIS TYPE OF CIRCUIT has inherent difficulties:

1) With usual high potentiometer impedances, pickup from stray electrostatic fields may necessitate shielding of the remote signal leads. Shielding and its capacitance increases phase shift.

2) In the summing resistor network, half of the error voltage appears across each resistor, so that only half of the error voltage appears at the amplifier input. This means a loss of gain of one-half, which must be made up by the amplifier.

3) To achieve terminal linearity and resulting servo accuracy, it is often necessary to end-trim conventional potentiometers.

CONTRAST THIS CIRCUIT WITH one which includes the Vernistat a.c. Potentiometer – a fundamentally new, compact device which combines several desirable features not available in standard potentiometers.



Here, a null transformer provides gain and transmits the error signal directly to the amplifier. Because of this, the amplifier gain requirements are reduced. The error signal is zero when the two Vernistat shafts correspond.

IN THE VERNISTAT CIRCUIT, all signals are transmitted over low impedance leads. This reduces the circuit's susceptibility to pickup and quadrature due to stray capacity. This is particularly important in high gain servo systems.

FEWER COMPONENTS ARE NEEDED with the Vernistat approach, and this reduces the system's complexity. Summing resistors are not necessary. Where conventional potentiometers must be end-trimmed to achieve terminal linearity, the Vernistat inherently provides terminal linearity by means of its design.

IN SOLVING DESIGN PROBLEMS like these, the Vernistat a.c. Potentiometer offers such major features as: low output impedance (as low as 45 ohms) with high input impedance (as high as 200,000 ohms) – high resolution (up to 0.004%) – low phase shift (as low as 0.2 minutes) – and high terminal linearity (to 0.01%). Vernistat a.c. Potentiometers meet the requirements of MIL E 005272-B, and will operate at 125°C without derating.

WRITE TODAY for full description and specifications on Vernistat a.c. Potentiometers, Adjustable Function Generators, and Variable Ratio Transformers.

*vernistat®—*a design concept that unites in one compact device the best features of the precision autotransformer and the multiturn potentiometer*

vernistat division

768 Main Ave., Norwalk, Conn.

Perkin-Elmer *Corporation*

CIRCLE NO. 70 ON INQUIRY CARD

COMPONENTS DIGEST

high precision in this size unit. Large production quantities have been manufactured to peak-to-peak tolerances of ±0.25%. These have also been capable of passing the most rigid military specifications such as MIL-R-12934, MIL-E-5272 and MIL-R-19518. This design has been engineered to provide a compensating output between the voltage resolution and the angular resolution. The shaped card permits the optimum design feature of balancing the maximum number of turns against the minimum variation in length of turn or incremental voltage output. Length of zero slope area at the 90° and 80° of sine function points is minimum, affording accurate conformance to the true sine-cosine function.

Fairchild's 3″ design has been used for extreme accuracies in multigang

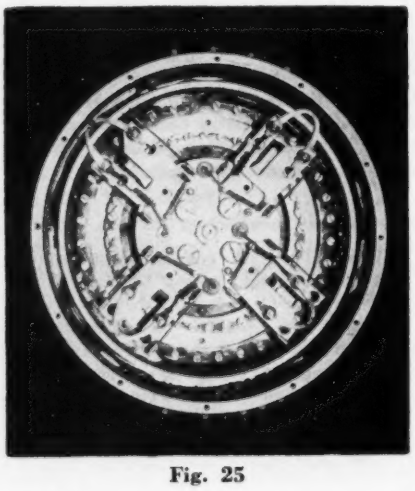


Fig. 25

Cam Correction System. A metal track, concentric with the winding, is supported by adjusting screws at regular intervals, control ing its elevation. A lever coupled to the rotor arm, rides on this track, and, following its profile, advances or retards the wiper relative to shaft rotation. Correction for the load and for inequalities in the winding or in mechanical construction is applied by adjusting the track level. For load/potentiometer ratios under 30.1. The load error is initially compensated by card shaping with final correction as above. This correction can also be adapted to offset external system errors. The track is rigidly held in head grooves on the adjusting screws thus assuring permanence of calibration and resistance to vibration up to services specifications. The potentiometer is calibrated on an optical dividing head with an accuracy of 6″ of arc, against a master potentiometer with a certified accuracy approaching 1 part in 100,000.

TABLE IV

Applications of Radio Frequency Resolver

(Suggested by Kearfott Division, General Precision, Inc.)

Oscilloscopic Sweep Circuitry

Radio Telemetry

Radar Display Circuitry

High Frequency Data Transmission

High Frequency Function Generators

High Speed Computers

sine-cosine performance. Ganging of six to eight cups is a common occurrence in this design, since high accuracies can be obtained even with the ganging procedures. Standard accuracies of ±0.35% are the usual requirement, but units have been manufactured with tolerances of ±0.25% or better. This unit also provides extremely high quadrant resistance and resolution which cannot be achieved in the smaller diameter units.

Their 5" design is used quite often as laboratory master pots to obtain high accuracies in the sine-cosine function. Accuracies of ±0.12% are normal outputs for this diameter unit and extremely high resistance and resolution can be obtained.

(These specific examples are intended to be typical, rather than inclusive. Complete data will be presented as indicated below, in Master Charts to be printed in the near future.)

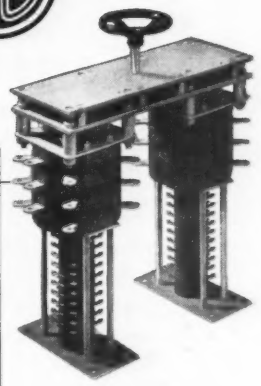
Of unusual interest is the cam corrected potentiometer by Colvern. This cam correction is adjusted to neutralize the inherent nonlinearity of the resistance wire and the cumulative tolerances in the mechanical assembly of the potentiometer providing functional accuracies approaching the resolution. Cam correction also serves to compensate for loading error with more accuracy than is practically possible by card shaping. It can, in addition, be adjusted to correct inaccuracies in the system external to the potentiometer itself. Sine-Cosine units have been constructed with 360° peak-to-peak conformities of ±.05%, and to ±.035% over a limited angular range. Fig. 25 shows how the cam construction works. Technology Instrument Corporation has applied radically new design techniques to development of sine-cosine potentiometers that will outlast virtually any system. These techniques previously applied to linear pots resulted in designs that showed no deterioration in performance after 85 million

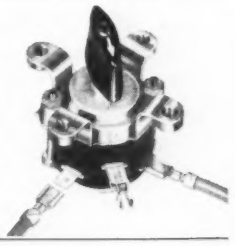
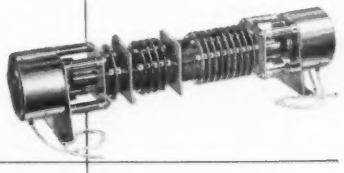
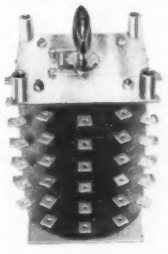
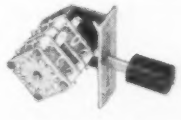
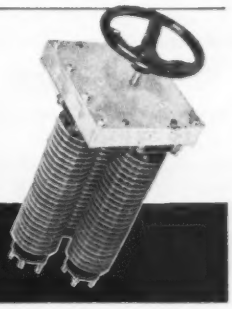
ROTARY multi-pole multi-circuit SWITCHES

— standard or special —
to meet your requirements and
MIL or BuShips specifications
for simple or complex circuit control.

Here are typical designs that show
the versatility of Esco construction.

Write for Bulletin 8A or call us for details.



Style and Size	Loads and Circuits	
Single-control tandem pair; snap-action; 7 × 19 inches × 20 inches behind panel. 75 lbs. approx.	200 amps. 500 v. a-c 6-pole, triple-throw; 30 amps. 500 v. a-c 20-pole, triple-throw.	
Quick-connect terminaling for snap-on wiring; 3¼ inches diameter, 3 inches behind panel. 8 oz. approx.	10 amps. 125 v. a-c single-pole 4-position; snap action.	
2-way drive by 6-volt solenoids; 3⅞ inches diameter, 18½ inches long. 12 lbs. approx.	10 amps. 125 v. a-c 34 poles, 2 positions.	
High-current low-voltage tap switch; 10¾ × 10¾ inches, 14 inches behind panel. 25 lbs. approx.	150 amps. 6 v. a-c 6-pole 12-position.	
Lever-actuated miniature switch; 1¼ × 1¾ inches. 1¼ inches behind panel. 2 oz. approx.	3 amps. 125 v. a-c 4-pole 3-position.	
3-gang, gear-drive single-control switch; 6⁹⁄₁₆ × 7¹⁄₁₆ inches × 14 inches behind panel. 25 lbs. approx.	5 amps. 125 v. d-c 75 poles 2 positions.	

ESCO of WEYMOUTH
ELECTRO SWITCH CORPORATION
167 King Avenue, Weymouth 88, Massachusetts

CIRCLE NO. 71 ON INQUIRY CARD

NEW

direct-current

TACHOMETER GENERATOR

permanent-magnet

APPLICATIONS

- **SERVOS** The highly linear output and wide speed range are ideal for velocity or integrating servos. Low driving torque permits its use as a damping or rate signal in all types of servos.
- **INDICATING TACHOMETER** Matching indicating meters available from stock in various speed ranges.
- **SPEED TRANSDUCER** Ideal for use as a speed transducer in connection with fast-response direct-writing oscillographs.

FEATURES

- **SIZE** Miniature. Approx. Dia. 1⅛".
- **OUTPUT** Various models with outputs as high as 24 v/1000 rpm.
- **LINEARITY** Linearity from 0 to 12,000 rpm is better than 1/10 of 1% of voltage output at 3600 rpm.
- **BRUSH LIFE** Better than 100,000 hours (10 years) of continuous operation at 3600 rpm.
- **BIDIRECTIONAL OPERATION** Output in either direction is held to a ¼ of 1% tolerance.
- **RIPPLE** The rms value will not exceed 3% of the d-c value at any speed in excess of 100 rpm.
- **CONSTRUCTION** Aluminum housings with protective treatment; stainless steel shafts; fully shielded ball bearings; Mylar insulation.

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CIRCLE NO. 57 ON INQUIRY CARD

COMPONENTS DIGEST

cycles at 500 rpm. T. I. C. fully expects to be able to run these pots in excess of 100 million cycles at speeds as high as 1000 rpm with no significant changes in performance.

The new design, called the Rotoflex$_R$ pot, employs a patented TIC capsule contact with a wirewound resistance element. The capsule contact illustrated in Fig. 26, consists of a gold foil contact diaphragm with a teflon-impregnated backing suspended above the resistance elements by concentric, insulated stand-off rings. The teflon-backed foil is depressed to make contact with the resistance element by the dimpling effect of a small-diameter rolling pressure piece as shown in Fig. 27. This dimpling action of the foil by the rolling pressure piece eliminates sliding action between the contact and the resistance element. Absence of sliding-contact action eliminates wear of the resistance element, which can cause change in the resistance and in linearity (conformity). Wear particles, dust, and debris are not present, which could cause erratic contact and noise. Wear of the diaphragm itself is prevented by use of the rolling pressure piece, which is a microminiature ball bearing or sapphire disc mounted in pivot bearings. In addition, the actuation torque of the pot is very low, due to the low friction offered by the rolling pressure piece to the teflon diaphragm. Ample pressure of the foil against the winding is thereby maintained, eliminating shock and vibration difficulties.

The capsule contact is normally sealed around the stand-off rings with epoxy potting compounds so that all of the active electrical part of the pot

Fig. 26 TIC's capsule contact with wirewound resistance element. The diaphragm is peeled back to show interior construction.

is protected from external dust and moisture. Mil E-5272 and Mil Std. 202 moisture resistance tests indicate no significant penetration of moisture to the contact area.

It is interesting to note that the gold foil acts not only as the winding contact, but also eliminates the need of slip ring contacts.

Properties of the epoxy-impregnated fibreglass backing are maintained over a temperature range of −55°C. to +150°C. The foil-epoxy fiberglass laminate was carefully selected to provide optimum resilience needed for proper dimpling action, but is stiff enough to prevent multiple bridging of foil to resistance element during shock, vibration or acceleration. Extensive Mil spec tests for shock, vibration, humidity, acceleration, and tempera-

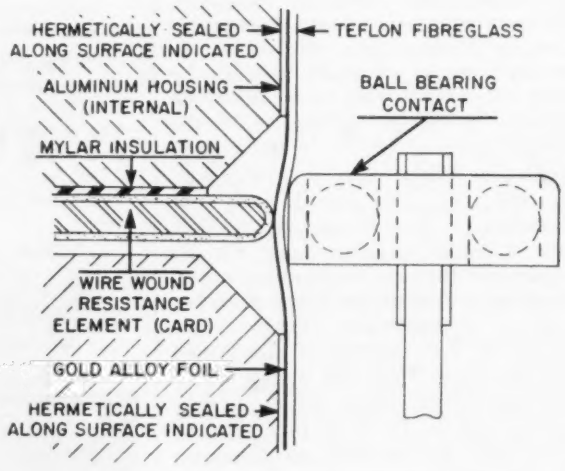

Fig. 27 Cross section view of TIC's capsule contact showing dimpling effect of rolling pressure piece.

ture have been performed to qualify use of the capsule contact in military applications. All of the prime advantages of wirewound resistance elements are retained in the Rotoflex$_R$ pot. Little loss of functional accuracy of the potentiometer in its assosciated network can be expected over the temperature range of −55°C. +150°C. due to the inherent low temperature coefficient of the wirewound resistance element: approximately 20 ppm/°C. Non-linear functions, multiple tapping, and varying resistance values are readily and economically produced. Resistance drift, less than 0.1% due to temperature cycling or heat exposure is low, as is thermal noise. Several watts power dissipation is typical; the substantial area of the card-type winding permits rapid dissipation of heat, so that excessive hot spots are not experienced.

The Rotoflex$_R$ principle is also being applied successfully to metallic film with comparable results, and will provide infinite resolution.

A significant characteristic of this design is that the noise decreases steadily with life. TIC's explanation is that the diaphragm shapes itself, by cold working, in the precise mold of the resistance element so that its contact to the resistance element at any point improves with life. This molding effect is essentially a microscopic condition since conformity (or linearity) and total resistance are little affected. They say that microscopic examination of the metal diaphragm after tests bears out this theory.

Our April 1960 issue will conclude this survey of Electrical Resolvers with a Master Chart of performance characteristics of commercially available varieties, and a Buyers Guide. Manufacturers who have not submitted data on their units are invited to do so.

WORTH FILING

Electrical Contact Design

A comprehensive engineering catalog is a general compilation of information on important aspects of electrical contact theory and practice to lend considerable assistance to the design engineer. Typical sections of the catalog include: electrical contact phenomena; design factors, selection, classification, and properties of contact materials; specific engineering data on precious metals and their alloys; contact backing materials; composite and laminated materials; and many other factors applicable to contact design problems.

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new

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These bearings feature: (1) light, one-piece retainer with true maximum ball complement — good for low torque values. (2) savings from 46% to 90% on space requirements, compared with conventional inch-series ball bearings of equivalent bore size. (3) no loading slot or other design compromise which might limit thrust capacity. (4) high ratio of load capacity to bearing volume. (5) rings and balls of stainless steel; retainer of pressure-molded fibre-reinforced phenolic. Made in precision and ultra-precision grades.

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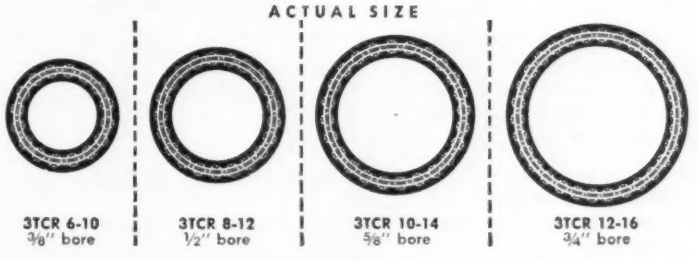

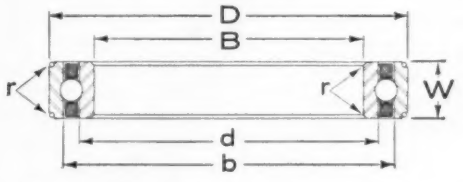

*B bore ± .0002	*D o.d. + .0000 − .0004	W width + .0000 − .0050	†r radius	b outer land ± .001	d inner land ± .001	Balls no.	Balls size	‡L lbs.	§S lbs.
.3750	.6250	.15625	.010	.542	.457	16	1/16	77	110
.5000	.7500	.15625	.010	.672	.587	21	1/16	89	144
.6250	.8750	.15625	.010	.797	.712	24	1/16	94	165
.7500	1.0000	.15625	.010	.922	.8375	30	1/16	101	206

Dimensions are in inches. *Tolerances shown are for Precision Grade. Write for Ultra Precision Grade tolerances. †r is maximum fillet radius on shaft or housing that bearing will clear. ‡Radial load capacity at 500 rpm and 2500 hours average life. §Static non-Brinell load capacity.

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Rugged Accelerometer

A miniature accelerometer features new all-steel construction to withstand wide temperature extremes. Providing linearity and accuracy to 1%, the units are hermetically sealed and employ a glass cylinder–carbon piston damper arrangement for almost zero friction. Humphrey, Inc., San Diego, California.

Circle No. 229 on Inquiry Card.

Instrument Motor

A new fractional watt d-c instrument motor combines small size and low power drain with high torque. Of unorthodox design the motor has neither revolving windings nor sliding commutator. An integral reduction gear assembly provides a wide selection of output speeds. Features are: rigid polyethylene case; alnico rotor, stainless steel shaft and ball bearings; unidirectional start, will not start if battery voltage is accidentally reversed; output torque up to 40 ounce inches at 1 rpm; no load current of approx. 10 milliamps at 6 volts. Brailsford & Company, Rye, N. Y.

Circle No. 230 on Inquiry Card.

Rotary Valve Actuator

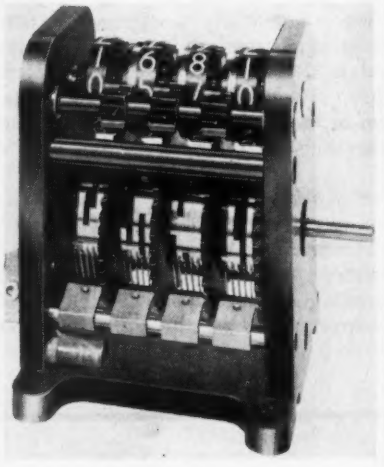
A low cost, high accuracy, rotary valve actuator that slips on the valve stem is only 4½" in diameter by 5" long and develops torques of 125 inch pounds. The unit provides full scale control in as little as 1 second with remote control accuracies of one part in 1,000. Low rotor inertia, damping and optional tachometer feedback provide optimum frequency response. The actuator features fully enclosed and lubricated gear trains, weatherproof construction (explosion-proof is also offered), choice of power supplies and a motor with ample heat sink to permit continuous operation at locked rotor current. The actuator may be pushbutton controlled from a 115 volt 60 cycle supply, or furnished with a dial type remote positioner. Automatic control is usually provided by a transistorized printed circuit amplifier which drives the motor control phase from last stage power transistors. Jordan Controls, Inc., Milwaukee, Wisc.

Circle No. 175 on Inquiry Card

Two-Speed Synchronous Motor

A new combination four and eight pole dual speed synchronous motor contained in a size 11 frame and within a length of less than 2 inches is capable of operating in an ambient temperature range of −55C to +85C. The motor meets the requirements of MIL-E-5400 and MIL-E-5272. Input voltage for either 12000 rpm or 6000 rpm speeds is 115 volts, 400 cycles, single phase. Pull-out torque for the eight pole unit is .10 oz-in. and the four pole unit .2 oz-in. Life expectancy is a minimum of 1000 hrs. Double sets of leads are provided for external switching. Total weight of unit is 3.8 ozs. Mechatrol, Div. of Servomechanisms, Westbury, L. I., N. Y.

Circle No. 193 on Inquiry Card.



Direct Reading Encoder

Direct drive counter provides simultaneous readouts in both visual and digital form. In a typical application, the unit's shaft is rotated by a temperature controlled servo, and when scale factors are selected which enable the unit's fu'l range to equal 100°C, both visual and electrical readouts to the nearest .01°C are provided. Electrical readouts can then be made available at some remote location for automatic printout of temperature. This and similar direct reading analog-to-digital converters can be supplied in servo packages to suit the user's application. Kearfott Co., Inc., Clifton, N. J.

Circle No. 132 on Inquiry Card

ous Motor

r and eight pole
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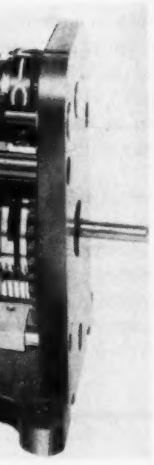

coder

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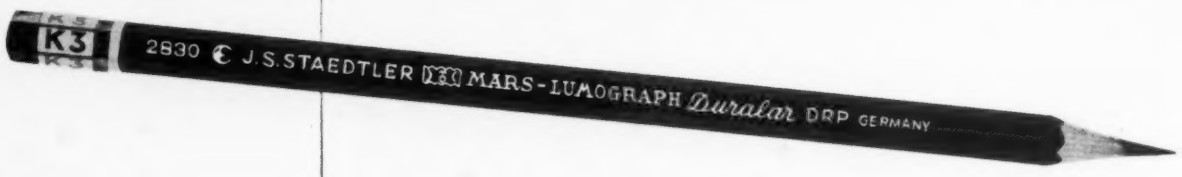
user's applica-
., Clifton, N. J.**

nquiry Card

CHANICAL DESIGN



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Duralar

Still the only pencil
that **can't smear** on Mylar,
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that **erases** on Mylar.
Duralar drawings on Mylar **reproduce** perfectly, **microfilm** without loss and can even be **cleaned** with soap and water.

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of Duralar pencil and leads and leading brands of matte-surface Mylar drafting film, just fill out the coupon and attach to your business letterhead.
See for yourself how the sensational new Mars Duralar solves your drafting problems. And Duralar is available (pencils, leads and lead holders) in five special new degrees of hardness (K1 to K5). Sold at leading engineering and drawing material suppliers.

NEW! No. 555 Duralar Eraser

Another first from
MARS

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Gentlemen: Please send me FREE
☐ Samples of revolutionary DURALAR pencil and lead
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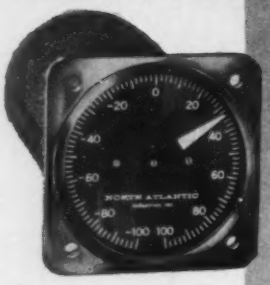
CITY _____ ZONE ___ STATE ___

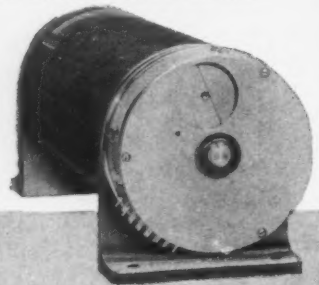
Servo Instrumentation for DATA CONVERSION



SERIES 200 SINGLE POINTER INDICATOR
For applications requiring accuracies and resolutions of less than .2% and high speed of response.

SERIES 200 DUAL POINTER INDICATOR
For high resolution and accuracy application where readability and dynamic response are important.

SERIES 300 DIGITAL DISPLAY INDICATOR
For highest accuracy and resolution.



SERIES 400 SERVO REPEATER
For general purpose repeater and digitizer applications where visual readout is not required.

A complete line of precision, high performance Servo Data Conversion Equipment designed to accommodate any input and output requirement.

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SERVO READOUT SYSTEMS

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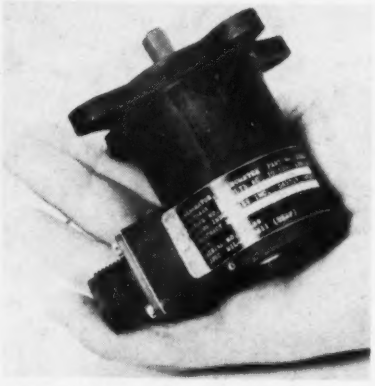
CIRCLE NO 50 ON INQUIRY CARD

ELECTROMECHANICAL COMPONENTS



High Temperature Tach Generator

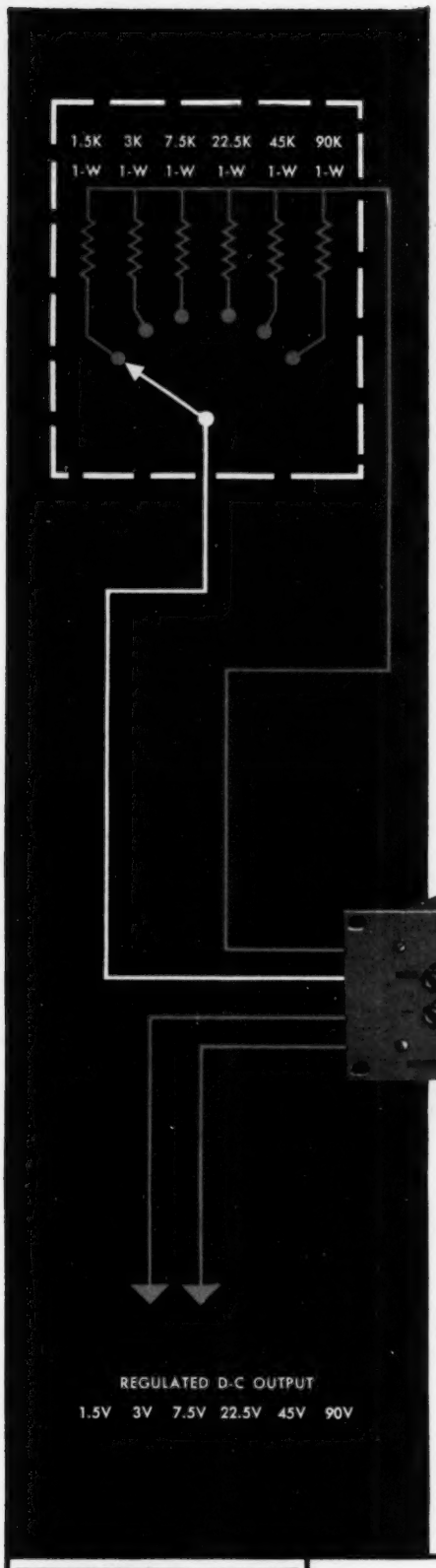
A new miniature tachometer generator was designed and tested under MIL-G-26611 and is smaller in size than previous models. A two-pole three-phase Y-connected stator and a permanent magnet rotor furnish alternating threephase output power with frequency proportional to rotor velocity. The generator is capable of 14 watts output at 4200 rpm and various outputs may be specified. The magnet is cast on the rotor shaft for added strength, and oversize ball bearings are used for long life. Globe Industries, Inc., Dayton, Ohio.

Circle No. 167 on Inquiry Card

Lever-Actuated Switch

Miniature switch provides multi-circuit control, panel-mounting, and lever operation in a compact unit suitable for low-power and electronic circuits. The assembly can be furnished with either one or two sections, giving up to twelve-pole switching. The lever actuator can be arranged to be spring returned to center from either or both of the two end positions or can be maintained in any or all of the three positions, or limited to two positions. Insulation of both stationary and movable contacts is molded of alkyd type MAI-60, per MIL-M-14E, and the basic switch is designed to meet MIL-S-3786. The electrical ratings are: 3 amperes continuous current at 115 volts a-c; interrupting rating, ½ ampere at 115 volts a-c; voltage breakdown 1000 volts RMS. All current carrying parts are silver-alloy material, assuring low contact resistance for the life of the switch. A "flying arm and star wheel" detent mechanism give positive non - hanging positioning. Electro Switch Corp., Weymouth, Mass.

Circle No. 145 on Inquiry Card



HOW TO BUILD A BATTERY BOX WITH RESISTORS...

it's easy with a

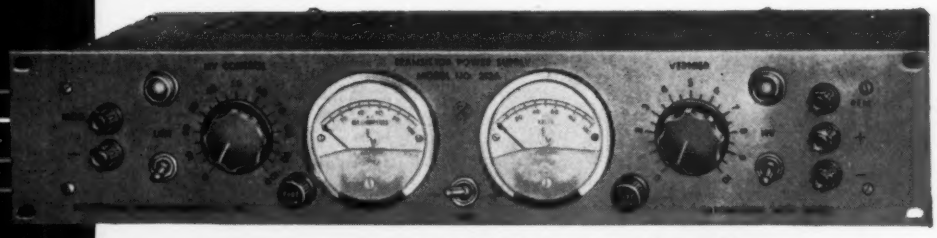
® Regatron Programmable Power Supply

Shunt the programming terminals of a Regatron Programmable Power Supply with a resistor, and you've set the output voltage to 1/1000 of the resistor's value. Yet the resistor carries no load current, does not affect regulation or maximum output current capabilities. Several resistors and a multiple-position switch make a compact "battery box" for the voltages you use most often . . . it's as simple as that.

In addition, you'll find that Regatron Programmable Power Supplies have all the other advanced features you would expect in a versatile laboratory instrument; super-regulation, vernier as well as main voltage control, and more. Compare a Regatron Programmable Power Supply with any other d-c power source, batteries included. You'll find you won't settle for less.

Regatron Programmable Power Supplies are available in voltage ranges covering 0-50 V dc, 0-100 V dc, 0-300 V dc, and 0-600 V dc. Current ratings are up to 3A, depending on model. Request Bulletins 350 and 765.

(Various models without the programming feature are also available in voltage ranges up to 1000 V and currents up to 1 ampere.)



TRANSISTOR TYPES

MODEL NUMBER	OUTPUT		REGULATION				MAXIMUM RIPPLE IN MV
			LINE 105—125 V AC 50—60 CPS		NO LOAD TO FULL LOAD		
	Voltage	Current	%	V	%	V	
212A[1]	0—100 V DC	0—100 MA	0.15	0.05	0.1	0.05	½
2-212A[1]	EQUIVALENT TO TWO MODEL 212A's. OUTPUTS MAY BE USED IN SERIES, PARALLEL, OR INDEPENDENTLY.						
224A[1]	0—100 V DC	0—200 MA	0.15	0.05	0.1	0.05	1
220A	0—50 V DC	0—500 MA	0.1	0.05	0.1	0.05	1
221A	0—100 V DC	0—500 MA	0.1	0.05	0.1	0.05	1
213A	0—50 V DC	0—1 AMP	0.1	0.05	0.1	0.05	1
214A	0—100 V DC	0—1 AMP	0.1	0.05	0.1	0.05	1
215A	0—50 V DC	0—3 AMP	0.1	0.05	0.1	0.05	1
218A	0—100 V DC	0—3 AMP	0.1	0.05	0.1	0.05	1

1. Modulation input provided for measurement of transistor parameters by small signal method.

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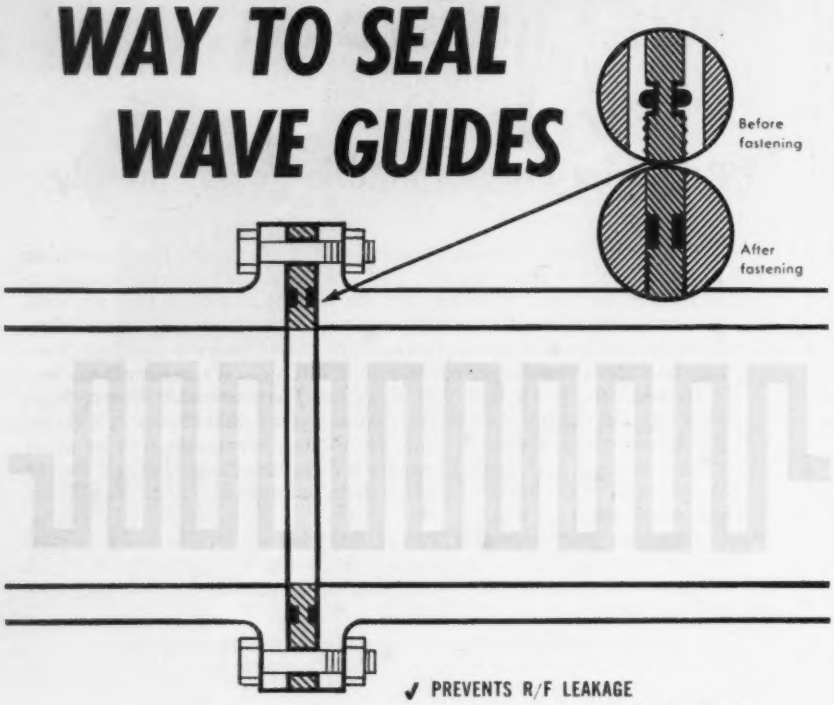
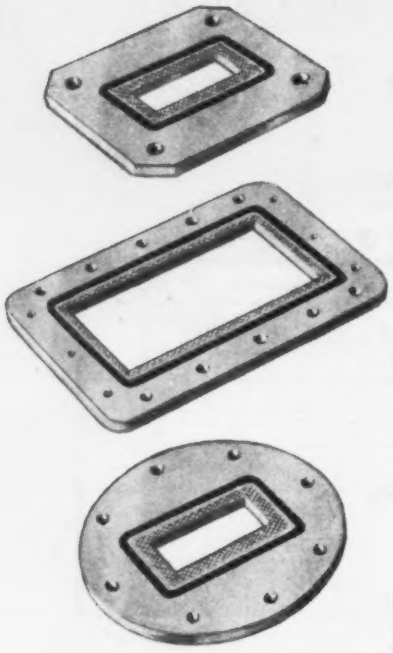
ELECTRONIC MEASUREMENTS COMPANY, INCORPORATED
EATONTOWN • NEW JERSEY

CIRCLE NO. 5 ON INQUIRY CARD

NOW THERE IS A BETTER WAY TO SEAL WAVE GUIDES





✓ **PREVENTS R/F LEAKAGE**
Metal-to-metal contact with "engraved fingers" on inside surfaces assures electrical continuity.

✓ **PROVIDES NO-LEAKAGE SEALING**
Controlled confinement of seal gland assures safe, sure, positive sealing — **exceeds** top hermetic specs!

✓ **ELMINATES ARCING AND/OR BURNING**
Designed to exacting requirements for proper mating of flanges as specified.

✓ **CAN BE RE-USED**
Seal is never "squeezed" beyond elastic limits, "memory" is constant, before, during and after fastening.

✓ **ECONOMICAL**
Eliminates cleaning or resurfacing flanges, no intricate machining required to accommodate the seal, and they're resuseable with just normal care.

✓ **STANDARDS FOR W/R SERIES**
Electr-O-Seals are available as standards to WR series Wave Guide flanges, assuring adequate supply and economy.

In addition to the standard WR series wave guide flange seals, Parker Seal Company also makes special seals to meet almost any specification or configuration. A nation wide group of field engineers are available to aid in expediting your requirements.

For more complete information send for catalog 5801.

Parker SEAL COMPANY
Culver City, California and Cleveland, Ohio
A DIVISION OF PARKER-HANNIFIN CORPORATION

CIRCLE NO. 49 ON INQUIRY CARD

ELECTROMECHANICAL COMPONENTS

Receptacles

Receptacles utilizing crimp-type, snap-locked contacts have been developed for use with plug-in relays and other plug-in components. Only as many sockets as are required need be inserted into the receptacle and they can be readily removed for circuit changes. Receptacles and contacts meet or exceed military specifications for voltage drop, dielectric strength, contact engaging and retention forces, corrosion resistance, and mechanical strength. Burndy Corp., Norwalk, Conn.

Circle No. 239 on Inquiry Card.

Magnetic Shield For Sensing Devices

Multi-cellular magnetic shield permits easy access to sensing devices used to measure low level magnetic reactions and gives complete protection against spurious readings by diverting extraneous magnetic fields. Stray magnetic fields are reduced to an extremely low level by a series of non-shock-sensitive non-retentive Netic Co-Netic containers, one within the other. These individual containers are separated and positioned by using epoxy casting resins. A one point ground system gives complete electrostatic shielding. Magnetic Shield Div., Perfection Mica Co., Chicago, Ill.

Circle No. 253 on Inquiry Card.

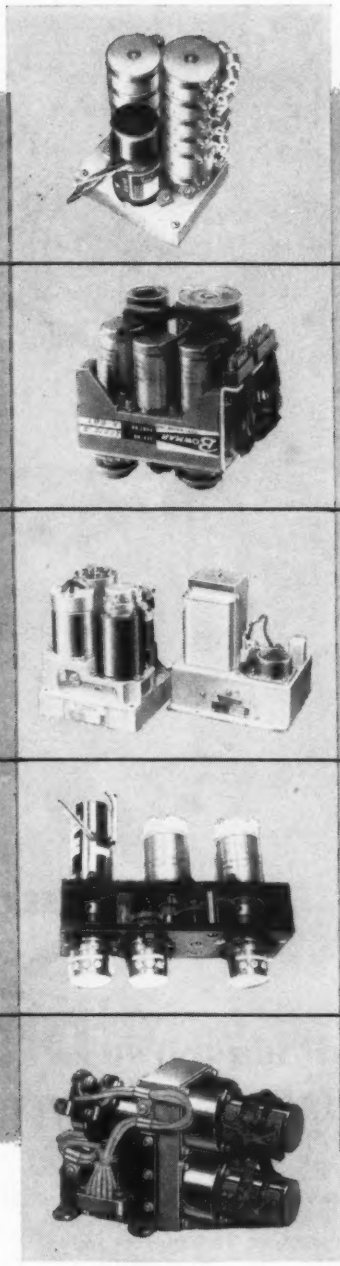
Toggle Switch

Modern design has invaded the switch industry and created a new look in toggle switches. Electrosnap Corp., Chicago, has just introduced a new toggle switch designed for control panels where appearance is important. In place of the conventional round bat handle and lock nut, Electros nap has substituted a sleek, chrome-plate handle with modern squared-off corners and flat sides. A highly polished, chrome plated jam nut fastens the 15/32 in. bushing to the panel. In addition to improving panel appearance, the new design permits greater travel of the bat handle (50° compared to 30°-35° on most toggles) and gives a more positive "feel" when the switch is thrown. Electrosnap Corp., Chicago, Illinois.

Circle No. 242 on Inquiry Card.

for control of the future...

...Precision Servo Packages by Bowmar



FOR SYSTEMS OF NAVIGATION, GUIDANCE, TRACKING, COMMUNICATION, DETECTION, RANGING, COMPUTATION

Original Bowmar concepts in servo design and packaging are playing an important role in space navigation to make "way-side" landmarks out of celestial bodies.

Achievement of these objectives becomes more evident as the nation's leaders in space and flight control systems increasingly utilize Bowmar's collateral engineering skills, production facilities, and servo packaging hardware.

With strong accents on **reliability,** Bowmar has step by step improved the state of the art in precision control, guidance, computation, and communications packages while contributing to extraordinary reductions in system weights and sizes.

Bowmar skills have been demonstrated repeatedly in systems for many of the nation's most important aircraft, missile, and rocket programs. This has been achieved by Bowmar's knowledgeable grouping or packaging of components into complete functional assemblies, ready to perform system **thinking processes.**

These engineering skills and expanding facilities are readily available to help reduce system weight and size while improving reliability.

Bowmar's technical and administrative staffs welcome the opportunity to demonstrate how these skills may be applied to your precision control, guidance or computation systems. Your specific inquiries are invited and will receive prompt replies.

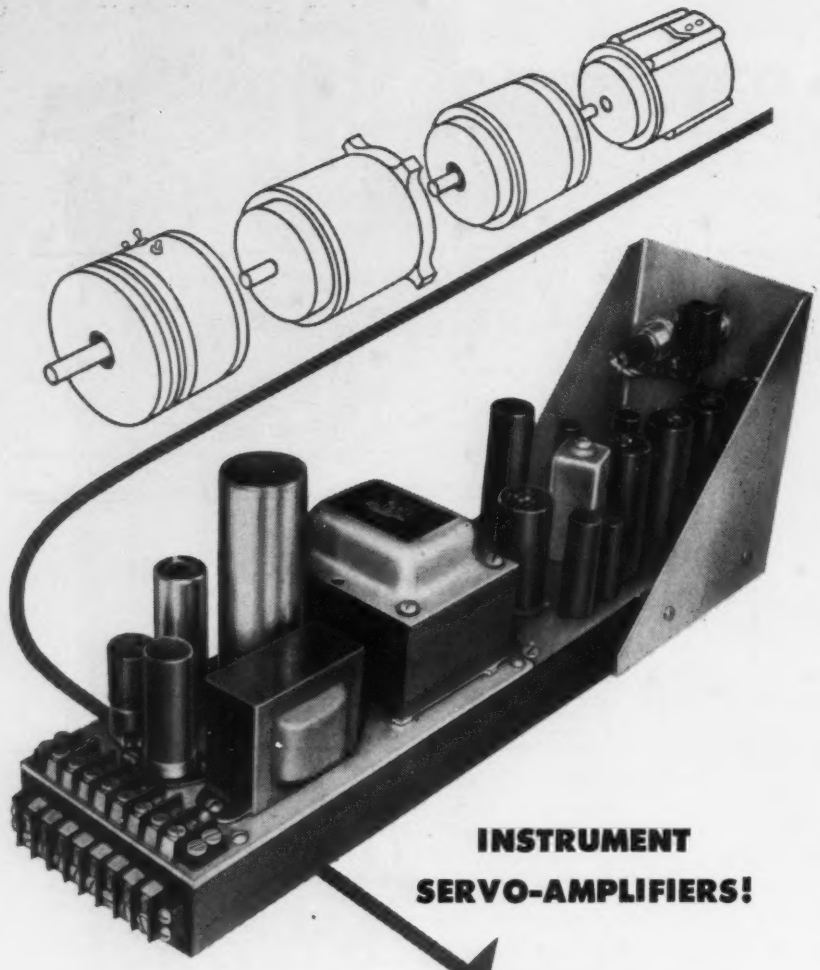
Write for Newest Handbook and Name of Nearest Bowmar Representative

BOWMAR INSTRUMENT CORPORATION

8000 BLUFFTON ROAD • FORT WAYNE, INDIANA

PRECISION ELECTROMECHANICAL CONTROLS AND INSTRUMENTATION, SERVOMECHANISMS, PRECISION MINIATURE GEARHEADS, NAVIGATIONAL COUNTERS, INDICATING DEVICES

CIRCLE NO. 6 ON INQUIRY CARD



INSTRUMENT SERVO-AMPLIFIERS!

an addition to the DIEHL* family of INSTRUMENT SERVO COMPONENTS

This new line of Instrument Servo-Amplifiers, coupled to an already established family of DIEHL Instrument Servomotors, Tachometers and Gear Reducers, further expands the new DIEHL concept of furnishing high quality servo components in modular form.

These units have been designed so that a true servomotor-amplifier combination featuring faster SERVO response is at last available from a single source of supply.

DIEHL Instrument Servo-Amplifiers are supplied in ratings suitable for driving the popular 1, 5 and 10 watt motors and use printed circuitry for high reliability.

FEATURES

- Standard rack mounting.
- Control adjustments for gain, phase, internal feedback, and external feedback.
- Push-pull output stage matched to motor control phase.
- A.C. or D.C. input.
- With or without integral power supply.
- Reliable, premium quality vacuum tubes.

Write for detailed information on this complete line of Instrument Servo Components.

DIEHL MANUFACTURING COMPANY

Electrical Division of THE SINGER MANUFACTURING COMPANY

Finderne Plant, SOMERVILLE, N. J.

other available components

• AC SERVOMOTORS • AC SERVOMOTORS WITH AC TACHOMETERS • DC SERVO SETS
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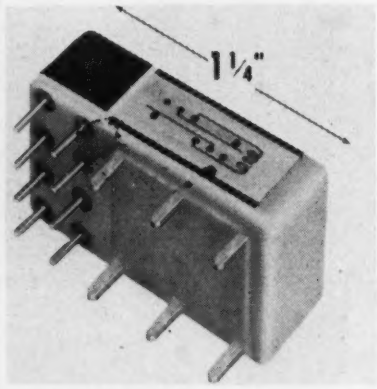
*A Trademark of DIEHL MANUFACTURING COMPANY †A Trademark of THE SINGER MANUFACTURING COMPANY

CIRCLE NO. 51 ON INQUIRY CARD



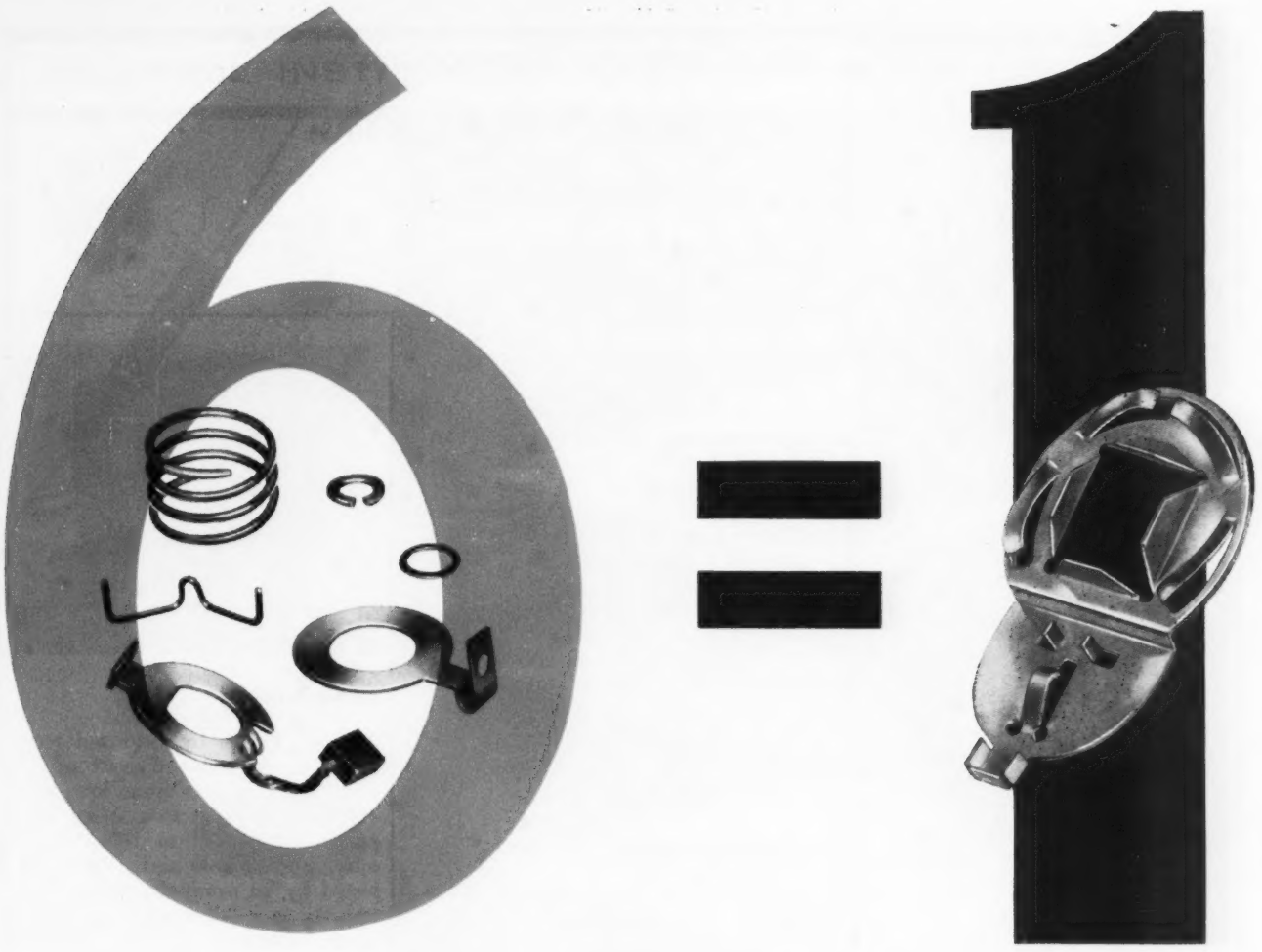
Micro Miniature Relay

Micro miniature relay has side mounting for printed circuit applications and is epoxy potted for maximum shock and vibration resistance. Designed with a minimum profile configuration for critical space and weight applications it is only 1¼ inches long and less than ½ inch high. Operating temperature range is −65C to +125C. It will withstand shock forces of 100g, linear acceleration of 100g, and vibration of 25g or 0.375 inch excursion over a full frequency range of 5 to 2,000 cps. Standard units meet the requirements of MIL-R-5757C and MIL-R-25018. At rated load, the relay will execute a minimum of 100,000 operations. Dielectric strength is 1,000 VAC RMS (60 cps). Insulation resistance is 1,000 megohms minimum. Pull-in time is only 7.5 milliseconds maximum under nominal voltage. Drop out time is 4 milliseconds maximum. The contact rating is 2 amps resistive (non-inductive) at 26.5 VDC. Contact arrangement is DP-DT. Coil ratings available from 4.3 to 108 volts dc. Special models available for dry circuits. Electronic Components, Subsidiary of Telecomputing Corp., No. Hollywood, Cal.

Circle No. 163 on Inquiry Card.

Low Cost Digital Voltmeter

A new, low-cost ($785) digital voltmeter with full four-digit resolution is designed for a wide range of d-c measuring jobs and, with accessories, a-c and low-level d-c measurements. The precision instrument features high input impedance and an average measuring time of 0.75 seconds per reading. Non-Linear Systems, Inc., Del Mar, Cal. Circle No. 231 on Inquiry Card.



with re-design 'rithmetic

One flat spring now does the work previously required of the six parts shown—and greatly simplifies assembly, too. This single multi-purpose spring (a) holds a carbon brush in a rheostat, (b) applies pressure on the wire windings, (c) provides friction detent action, (d) acts as a retainer on the rotating shaft.

How did this come about? The maker of the rheostat undertook a complete redesign analysis, called in an A.S.C. Spring Engineer when it concerned the spring.

Early consultation with A.S.C. springmakers in new or redesign projects gives greater range to plans, safeguards against high production costs. Our booklet, "Designing Springs for Performance," may help you. Write for your copy.

5902

Associated Spring Corporation

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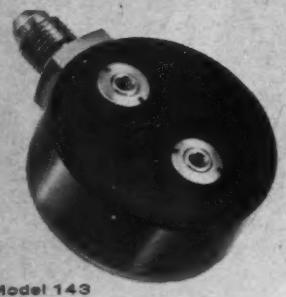
CIRCLE NO. 72 ON INQUIRY CARD

PRESSURE TRANSDUCERS



Model 143

MISSILE, AIRCRAFT AND INDUSTRIAL APPLICATIONS

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CIRCLE NO. 52 ON INQUIRY CARD

New Electronic Components For Electromechanical Systems

Improved Solar Cell

Silicon solar cells for space vehicles, incorporating an extremely thin, optically coated coverglass and providing optimum reflection properties and high thermal emissivity, are capable of providing (1) reduced cell temperature and greater efficiency through increased radiative thermal emissivity; (2) protection of cell surface from micrometeorite bombardment and abrasion; (3) reflection of that portion of the solar spectrum not effective in solar cell electrical conversion, and (4) furnishing an anti-reflection surface to improve the transmission of desired radiation. International Rectifier Corp., El Segundo, Calif.

Circle No. 238 on Inquiry Card.

Gridded TW Tube

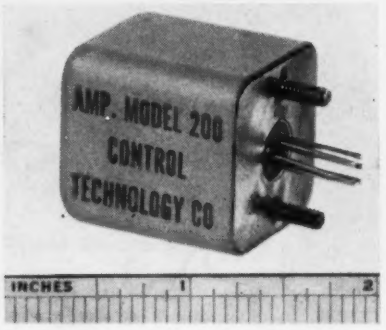
A new traveling wave tube combines a periodic focused permanent magnet with a gridded gun to produce a traveling wave amplifier exhibiting full one-kilowatt power output characteristics with low power consumption. Use of a control grid enables the tube to operate with a very fast response time and with simpler modulation problems. Peak output is in excess of 1 kw at only 0.5 w input. By cascading two tubes an output of 1 kw can be obtained with less than 0.5 mw of drive. Hughes Products, Electron Tube Division, Los Angeles, Cal.

Circle No. 233 on Inquiry Card.

One Megohm Resistor

New winding techniques using a 0.0005 inch diameter resistance wire produces a one megohm resistor. Density of resistance by cubic inch is twice as high as on miniature micromodules now being used in miniaturization programs. Previous maximum resistance for a unit of this size was 250K. Dimensions are 3/16" diameter by ⅜" length, with a maximum wattage rating of 0.25 watts. Resistance tolerances as close as 0.01% can be obtained. Temperature coefficients as low as ±3 PPM/°C can be obtained. It meets all characteristics of MIL-R-93B, Amendment 3, except physical size. Daven Co., Livingston, N. J.

Circle No. 254 on Inquiry Card.



Servo Amplifier

1" x 1" x 1⅛" transistorized servo amplifier can drive 2 watt or 3.5 watt servo motors from low level 400 cps signals at an ambient temperature of −55C to 125C. Maximum gain is 2500 and may be adjusted by an external resistor. Gain stability is a 2db over temperature range. Internal limiting prevents overdrive or phase shift for high input signals. Operating on 28 volts d. c., the unit is completely potted meeting MIL E 5272 A. Output impedance of the amplifier is only 50 ohms. Control Technology Co., New York, New York.

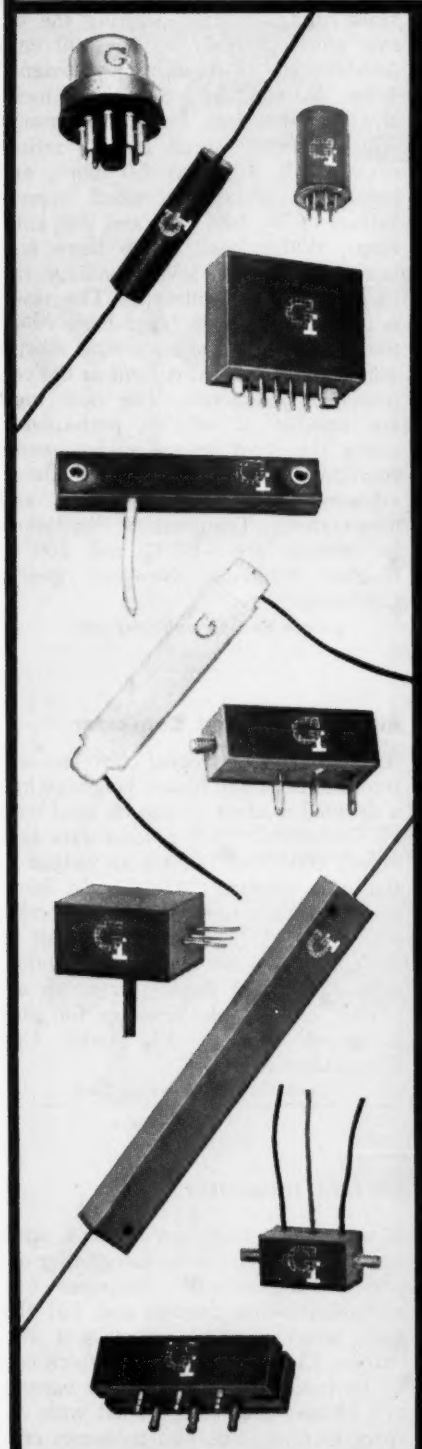
Circle No. 187 on Inquiry Card.

PNP Switch Transistor

A new line of PNP silicon high speed switching transistors provides a range of betas from 15 to 50, a range of collect-or-to-emitter voltages from 15 to 50 volts, maximum emitter-to-base voltage of 5 volts, power dissipation of 250 mw, and a power derating of 1.8 mw/°C. DC current gain for the type is 50 (with I_C at 10 ma and V_C at 1 volt). Ac current gain is a minimum of 40 (with V_{CB} at 5 volts dc, and I_E at 2ma). The units have been designed primarily for high speed switching applications at low and medium power levels. The silicon double diffused mesa construction gives the transistors exceptional stability over a wide temperature range from −65°C. to +160°C. Hughes Air-Craft Company, Newport Beach, Cal.

Circle No. 170 on Inquiry Card

GENERAL INSTRUMENT SEMICONDUCTOR DIVISION



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GENERAL INSTRUMENT

PACKAGED ASSEMBLIES

Silicon Rectifiers

Silicon and Germanium Diodes

in any shape . . . in any circuit configuration

Want semiconductors in a special package? General Instrument will make up rectifiers and diodes in any packaged assembly needed to fit your specific requirements. Units can also include resistors, capacitors, etc. to produce complete circuit packages if you desire.

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CIRCLE NO. 74 ON INQUIRY CARD

ELECTRONIC COMPONENTS

Micro Miniature Diode

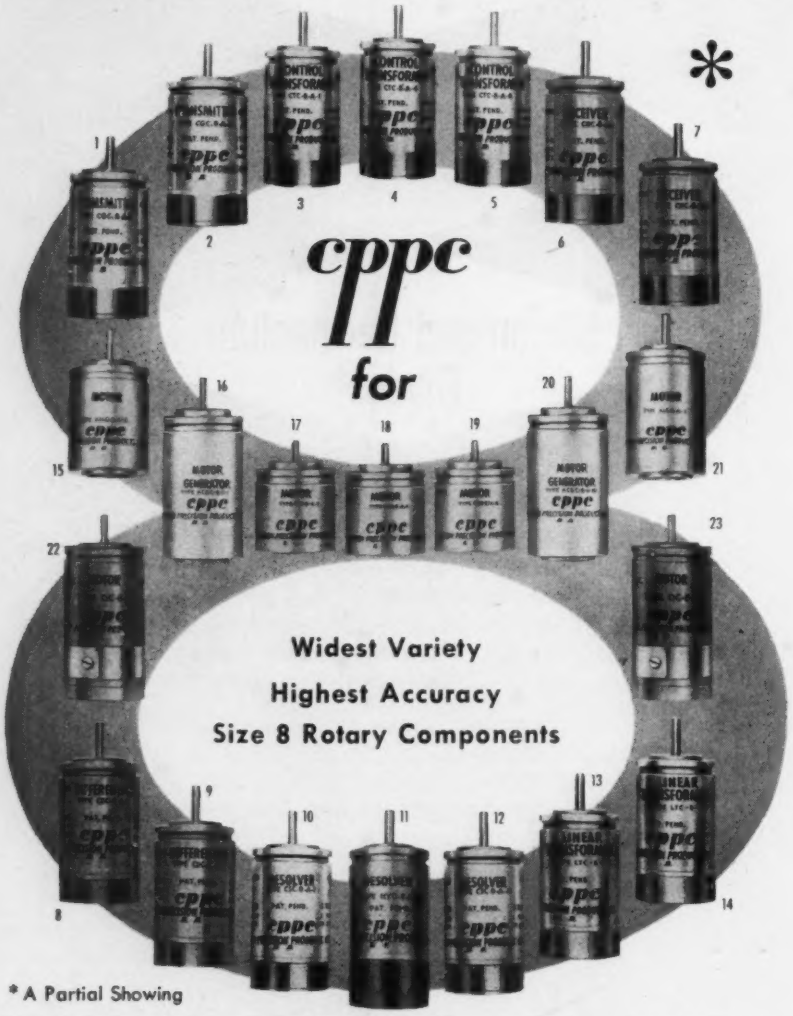
A new point contact microwave mixer for use in the Ku band region is part of a line of micro miniature diodes. The units meet the performance requirements of conventional ceramic or metal microwave diodes up to ten times their size. The maximum conversion loss of the new silicon diode is less than 7.5 db whereas the output noise ratio does not exceed 2.5 times. Sylvania Electric Products Inc., New York, New York.

Circle No. 171 on Inquiry Card

Magnetostrictive Delay Line

A new, variable magnetostrictive delay line with delays ranging from 2 to 20 microseconds, features high resolution. The unit accepts input pulse voltages of 5 v peak and input pulse widths of 1 microsecond (±) 0.2 microseconds. Output pulse voltage is in the order of 10 millivolts. Spurious response is kept 17 db down. Input and output impedance is 700 ohms. Conforming to all applicable mil specs, the line is hermetically sealed and ruggedly constructed. Operating temperature range is from −55°C to +85°C. Control Electronics Company, Inc., Huntington Station, Long Island, New York.

Circle No. 157 on Inquiry Card



* A Partial Showing

Clifton Precision's size 8 rotary components have been tried and proven by customers over the past 4 years. More than 50,000 have been shipped. These are the most accurate and best tested (because they are use tested) size 8 rotary components on the market today.

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CIRCLE NO. 75 ON INQUIRY CARD

Minute Rectifiers

Subminiature silicon rectifiers with inverse-voltage ratings covering the entire spectrum from 50 to 1000 volts include over 44 diode types (assigned Jedec No.'s 1N846 to 1N889 inclusive) divided into four basic groups, with maximum surge current ratings of 0.5, 1.0, 1.5, and 2.0 amps, and maximum average rectified current ratings of 50, 100, 150, and 200 milliamps. Within each group there is a complete range of inverse voltage ratings, in 100-volt intervals. The result is a matrix of diode types from which the designer may choose, with inverse voltage and rectified current as the two principal parameters. The new units are capable of reliable performance under the most severe environmental conditions, including those of shock, vibration, salt spray, humidity and temperature. Temperature limitations for storage are −65°C and 200°C. Hughes Products, Newport Beach, California.

Circle No. 154 on Inquiry Card

Binary-to-Decimal Converter

A new binary-to-decimal converter will translate from any binary language into a decimal readout. It can be used with all computers which process data in a binary code and require an output in the more common decimal code. Semiconductors are used for all conversion and memory functions. The unit is available as a single plug-in module with illuminated display or as an assembly of multiple modules for rack mounting. Hermes Electronics Co., Cambridge, Mass.

Circle No. 148 on Inquiry Card

Current Integrator

New current integrator with a wide current range and large integrating capacity, simultaneously measures (1) an instantaneous current and (2) the time integral (total charge) of this current. Any physical event which can be represented by an electric current can be measured and totaled with respect to time. The unit measures currents from 0.003 microamperes to one milliampere. Total charges up to 50 ampere-seconds can be measured directly. Higher charges can be recorded with external control. It utilizes modular packaging with all basic elements mounted on plug-in circuit cards. Standard instruments can be modified easily to meet unusual measuring requirements. Eldorado Electronics, Berkeley, Cal.

Circle No. 164 on Inquiry Card.

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PULL

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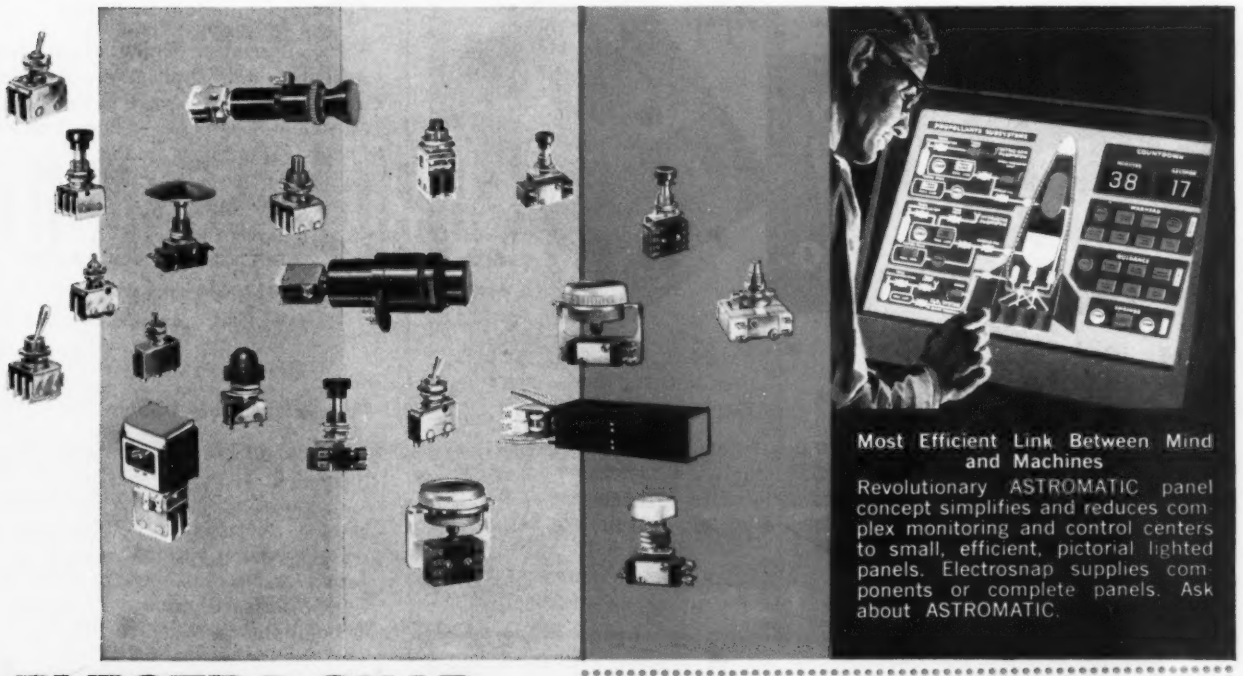

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ELECTRONIC COMPONENTS

New D. C. Power Source

A fail-safe power supply operated from a-c power is generally used where d-c power is needed which will be sustained if and when the a-c power is interrupted. It is also used for low voltage, high capacity d.c. reference voltage applications. The unit has an output voltage of 6.0 volts d-c, but by merely removing cells, other voltages of 4.8, 3.6, 2.4, and 1.2 volts d-c are available. Its total capacity is 450 milliamp-hours at a 10 hour rate without a-c. For extremely severe load conditions, it will supply 4 amps for short periods. Power input rate for charging purposes is adjustable to 0.006, 0.012, and 0.018 amps. Weight is 18 ounces, including cells, and the unit is approximately the size of an a-c outlet cover. If load conditions are such that the total drain is too high for one unit, it is possible to parallel several without alterations or adjustments. The power supply requires little or no servicing after installation and tests show that it can operate unattended for five years or more. American-Monarch Corp., Minneapolis, Minnesota.

Circle No. 260 on Inquiry Card.

Mesa Transistors

Because of unique design features, two newly-developed silicon mesa transistors have an unusually high small signal current gain. Either of the devices will replace up to three transistors of the same classification in many circuit applications. The new diffused junction, drift field mesa transistors (JEDEC No.'s 2N696 and 2N697) are designed for use as high speed switching units operating at medium power levels and as very high frequency amplifiers. A unique, U-shaped base-emitter configuration allows for the first time utilization of virtually all the transistor's emitter area. The minimum high frequency gain at high currents is 6 or more at 20 megacycles. This higher gain is due to tighter control of the base width in fabrication. The transistors are capable of useful current gains at 40 megacycles, indicating efficient operation in the ultra high frequency band when operated in a grounded base configuration. The photographic technique used in fabrication instead of conventional mechanical methods, gives greater precision of geometric control and results in better and exceptionally uniform characteristics. Hoffman Electronics Corp., L. A., Calif.

Circle No. 204 on Inquiry Card.

Miniature Voltage Regulators

Transistorized regulator is designed to operate in ambients of −55 to +125°C and to meet MIL-E-5272. Available output voltages are between 35 and 150 volts d-c at load currents up to 500 ma. Regulation is 0.1% for input variations of ±20% and load variations from zero to full load. Models with 0.05% regulations are also available. The unit measures 2½ x 2½ x 2¾ in. and weighs 15 ozs. Power-tronic Systems, Inc., New Rochelle, N. Y.

Circle No. 142 on Inquiry Card

Switching Transistor

Designed to meet specification MIL-T-19500/67 (SigC), a new transistor has a 5 amp maximum current rating and a maximum collector-base voltage rating of 80 volts. The unit will readily dissipate 35 watts at 25°C mounting base temperature. Stringent environmental testing required by the specification assures the high reliability demanded in military applications. Bendix Aviation Corp., Long Branch, N. J.

Circle No. 232 on Inquiry Card.

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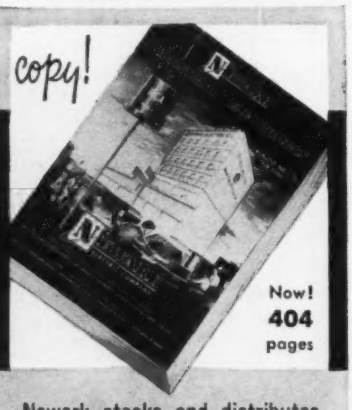

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TRIMPOT® MODEL 220

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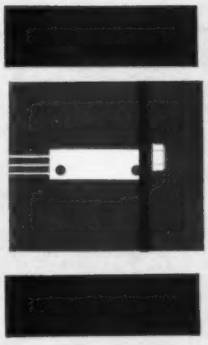

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CIRCLE NO. 4 ON INQUIRY CARD

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SIZE 8 SYNCHRO
(ACTUAL SIZE)

SIZE 8 SYNCHROS

IMC TYPE AND MODEL NO.	INPUT VOLTAGE 400	INPUT CURRENT AMPS	OUTPUT VOLTAGE VOLTS	PHASE SHIFT Deg. Lead (Max.)	IMPEDANCE Ohms Zro	Zss	NULL ERROR
TORQUE RECEIVER	ROTOR AS PRIMARY						Maximum Signaling Error
9708-001	26	.31	11.8	12	43+j170	35+j90	1°
TORQUE TRANSMITTER							
9708-002	26	.34	11.8	12	45+j170	30+j70	1°
9708-032	26	.12	11.8	11.8	48+j215	11+j25	1°
008-235	26	.10	11.8	12	54+j250	12+j45	1°
008-236	115	.03	90	12	660+j2650	810+j2700	1°
008-239	115	.04	90	12	910+j3605	650+j1545	1°
008-244	26	.004	11.8	12	68+j270	12+j45	5°
CONTROL TRANSFORMER	STATOR AS PRIMARY						
9708-007	11.8	.607	22.5	12	1080+j7500	610+j1565	1°
9708-035	11.8	.139	23.5	12	150+j600	27+j81	1°
008-334	11.8	.079	22.5	12	540+j1800	90+j360	1°
008-338	11.8	.074	23.5	12	410+j2700	130+j390	5
008-337	90	.024	97.3	12	470+j1770	810+j2700	10
008-340	11.8	.055	23.5	12	410+j2700	130+j360	1°
008-343	11.8	.135	23.5	12	140+j560	27+j81	1°
RESOLVER TRANSMITTER							
9708-004	11.8	.100	21.2	22	200+j400	50+j105	1°
VECTOR RESOLVER							
9708-008	11.8	.120	23	12	300+j400	27+j81	1°
LINEAR TRANSFORMER	ROTOR AS PRIMARY						
9708-009	26	.110	—	19	90+j330	60+j180	—
9708-026	26	.120	—	16	80+j320	90+j180	—
CONTROL DIFFERENTIAL	STATOR AS PRIMARY						
008-606	11.8	.120	22.2	12	60+j180	27+j81	1°

SIZE 11 SYNCHROS

IMC TYPE AND MODEL NO.	INPUT VOLTAGE 400	INPUT CURRENT AMPS	OUTPUT VOLTAGE VOLTS	PHASE SHIFT Deg. Lead	IMPEDANCE Ohms Zro	Zss	Zss	NULL ERROR
CONTROL DIFFERENTIAL	STATOR AS PRIMARY							
011-603	—	90.5	180	90.5	5.0	180+j1080	180+j1080	1°
9711-019	26V 115V 4c	11.8	115	11.8	8.5	55+j330	27+j54	1°
CONTROL TRANSMITTER	ROTOR AS PRIMARY							
9711-021	26	180	11.8	5.0	31+j186	10+j75	41+j82	1°
9711-020	26V 115V 4c	115	90.5	8.0	430+j2623	360+j1350	600+j1800	1°
TORQUE TRANSMITTER								
9711-001	—	110	180	90.5	7.5	770+j4720	290+j1350	1°
9711-021	—	115	347	11.8	6.9	600+j2700	54+j27	1°
011-201	115V 117V 4c	115	180	90.5	8.5	600+j2700	360+j1350	1°
9711-020	26V 115V 4c	26	180	11.8	8.5	54+j330	54+j54	1°
TORQUE RECEIVER								Maximum Signaling Error
011-103	115V 117V 4c	115	180	90.5	5.0	180+j1080	180+j1080	1°
9711-005	26V 115V 4c	26	180	11.8	8.0	54+j330	54+j54	1°
CONTROL TRANSFORMER	STATOR AS PRIMARY							
9711-030	26V 115V 4c	11.8	180	90.5	5.0	140+j720	36+j216	1°
9711-010	115V 115V 4c	90.5	354	97.5	8.5	181+j1018	60+j360	1°
RESOLVER TRANSMITTER								
9711-002	—	360	360	75.5	7.5	180+j1080	810+j2700	1°
ELECTRICAL R.SOLVER	ROTOR AS PRIMARY							
011-014	—	26	180	172	9.5	180+j1080	—	—
SECOND RESOLVER								
011-407	—	180 @ 1000 cps	180 @ 13 MIL ELECTRICAL ZERO	90 DEG. CW BETWEEN 0 - 40°	1:1 @ ELECTRICAL ZERO	2k	—	—

Nominal null values 25 to 125 millivolts depending upon unit.

Write for Size 8 Bulletin 204, and/or Size 11 Bulletin 206

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For Your 3-Ring Binder

NEW DATA SHEETS

For your free copy of the data sheets listed on this page, circle the appropriate number of the item on the Inquiry Card.

PNP Power Transistors 249

Specification data on a series of power transistors with a typical current gain of 40 at 10 adc and a maximum current rating of 15 adc. The series have four different voltage breakdown ratings to eliminate the danger of burnout. The current gain range is controlled for matching. These transistors are capable of switching up to 1000 watts and feature welded construction with a vacuum-tight seal. Bendix Aviation Corp., Red Bank Div., Long Branch New Jersey.

Magnetic Memory Stacks 252

Technical bulletin describes apertured ferrite plate, memory stacks, a line of miniature plug-in magnetic storage modules for use in high speed, coincident-current, random access memories and serial buffers. Included are description of the compact plug-in construction, the conventional coincident-current selection scheme, and the use of the 0.87" square apertured ferrite plates as the storage medium for the memory stacks, which range in capacity from 256 to 4096 words and 4 to 16 bits per word. Rese Engineering, Inc., Philadelphia, Pa.

Small Pressure Switch 258

A new sub-miniature, adjustable pressure switch exceeds the requirements of MIL-E-005272B for performance up to 200 psi under vibration, shock, and acceleration test conditions. The volume of the switch is less than 1 cubic inch and weight is only slightly over 1 ounce. A Ni-Span C pressure capsule and a snap-action switch are contained in an all stainless steel housing. The pressure-setting adjustment is simple, and the setting is positive, even under severe shock and vibration conditions. Pressure ranges and other information are available in a new bulletin. Bristol Co., Waterbury, Conn.

Phase Sequence Relays 257

Relays offer automatic monitoring of three phase power. Unit senses the phase sequence, and operates to close a contact when the applied phase sequence is a-b-c. The relay contact in a resting state is open, thus making the unit fail-safe. The contact remains open (non-operative) with the phase sequence of a-b-c on when any lead, or any combination of leads, are open and/or grounded. Bulletin gives specification of units available in 6 voltage frequency ranges. Master Specialties Company, Los Angeles, California.

Power Supplies 255

Among many exclusive features claimed to be offered for the first time in a semiconductor power supply of this type are —50% reduction in volume and 60% increase in efficiency over comparable vacuum tube supplies; high temperature silicon rectifiers; unique transistor regulator requiring no d-c fuse; short circuit damage proof; temperature compensated silicon diode voltage reference. Complete specs are given. Power Sources, Inc., Burlington, Mass.

Shock Tester 214

Performing an accurate, reliable, test cycle every minute a shock tester, in addition to producing the shock patterns outlined in military procurement specifications, is well suited for investigating problems involved in testing the protective value of packaging materials and methods. The unit is supplied complete with specimen carriage, control center and connecting hoses, and a dual purpose metering pin. Bulletin contains operational analysis, features and specifications. Consolidated Electrodynamics Corp., Rochester Div., Rochester, N. Y.

Electronic Sensing Control 256

New security electronic sensing control for detecting, counting, measuring and recognizing objects as they enter a capacity field is covered in 2-page bulletin. Completely described are method of operation, details of components and 16 applications accompanied by four diagramatic illustrations. Security Controls, Inc., Buffalo, New York.

Sensitive Relays 251

4 page bulletin describes a series of relays ranging upward from 1 milliwatt with contact arrangements from 1 Form C through 4 Form C. In-put powers, contact rating, coil resistance, enclosure dimensions, mounting arrangement, terminal styles and weight are included. General Automatic Corporation, Mountain View, Wayne, New Jersey.

Flexible Epoxy Resins 250

Technical sheets describe the many advantages of using flexible epoxy resins for potting electrical connectors and cable junctions. Advantages include: the epoxy, contained in a two part, preproportional cartridges, is ready to use; elimination of weighing, mixing, de-airing; no outside contamination. Electronic Production & Development, Hawthorne, Cal.

Integrating Motor Generator 247

Said to be the smallest unit of its type currently available, a servo motor integrating generator is thermisor compensated and characterized by an input of .5v/1000 rpm, linearity of .06% from 0-3600 rpm, and output variation of temperature. (—15°C to +75°C) of ±4% from the value at 25°C. Complete design data given. Kearfott Co., Inc., Little Falls, N. J.

Resins, Foams and Bonds 181

A new bulletin containing selector charts for potting compounds, coatings, foams and bonding agents can help the designer pick the exact resin that will best fit his needs. Definitions are provided for such terms as casting, encapsulation, impregnation, and coating and the charts offer hard, semi-rigid and flexible formulations for each of these applications. Plastic Associates, Laguna Beach, Cal.

Sub-Miniature Connectors 129

Two new sub-miniature electrical connectors for applications requiring extreme miniaturization are 29 and 75-contact units with reversed guides or patented polarizing screwlocks. Electrical and mechanical ratings meet or exceed MIL-C-5015 and MIL-C-8384. Breakdown at sea level is 1900 volts rms. current rating 5 amps. Data sheet contains specifications and complete description. DeJur-Amsco Corporation, L. I. City, New York.

Limit Switches 180

Data sheet describes two new, oiltight, maintained-contact, yoke-actuator switches. When moved from either extreme position toward the other, the actuator causes the internal switching unit to transfer when a reciprocating member must operate the switch when moving in one direction and reverse it when moving in the other direction. Actuator heads of these switches may be mounted in four positions, 90° apart. The yoke actuator may be rotated 360°, positively locking in any position. Micro Switch, Freeport, Illinois

Hysteresis Synchronous Motors 207

Features of a new line of extreme precision, hysteresis synchronous motors are explained in a 4-page illustrated brochure. The motors are insensitive to line or power supply voltage variations and a unique axial air gap design provides high torque, light weight and simplified construction. Detailed performance characteristics and dimensions are included in the brochure. Hysyn Electromotive, subsidiary of Telecomputing Corp., Los Angeles, Cal.

Tape Transports 182

Magnetic tape loop transports and reel-to-loop adapter are shown in specifications sheets. Three instrumentation-grade transports are listed, for maximum loop lengths of 35, 80 and 100 feet. Adapter converts reel transports to run 2½ to 15 foot loops. Memory, time delay and wave analyses are among applications described, and included are threading and looop-playing-time charts. Minneapolis-Honeywell Regulator Company, Beltsville, Maryland.

Germanium Diodes 183

Brochure covering a line of germanium gold bonded diodes includes descriptions of mechanical, electrical, and hermetic seal tests to which the diodes are subjected, also specifications and characteristic forward and reverse curves. General Transistor Corporation, Jamaica, New York.

3 Phase Voltage Regulation 248

How to use single-phase a-c line-voltage regulators to accomplish effective voltage regulation in three-phase circuits is the subject of new bulletin. Phase-shift relations between input and output are discussed, and the results of laboratory tests are described. The limitations of "open-delta" connection are explained. Sorensen & Company, South Norwalk, Conn.

Trimmer-Potentiometer 174

Sub-miniature trimmer-potentiometer has resistance range from 10 ohms through 100,000 ohms with ±5% standard tolerance, in case size 0.890 x 0.210 x 0.312, and 0.750 mounting hole centers for two No. 2 screws. The unit dissipates full two watts to 70C, derating linearly to zero at 200C, and withstands extreme conditions of humidity, vibration, shock, acceleration, salt-spray and altitude. Available in side-mounted printed-circuit configurations, as well as flexible wire leads, or solder-lugs; and panel-mount hardware may be incorporated on all styles. Atohm Electronics, Sun Valley, California.

(Continued on Page 90)

2 IMPORTANT TOOLS FOR HIGH VACUUM PRODUCTION—

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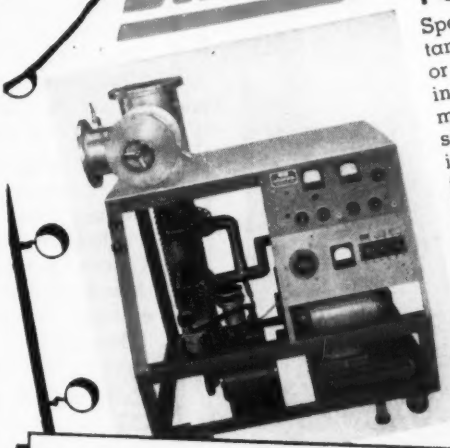

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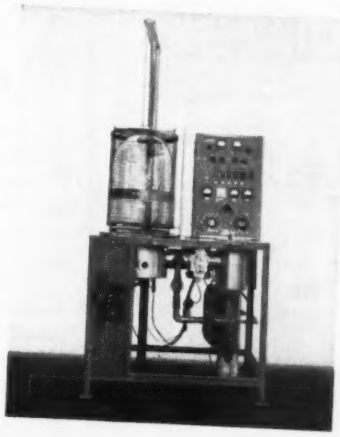

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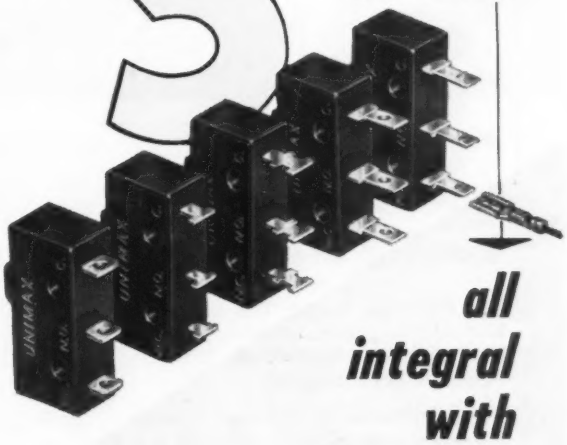
*See Previous Issue

UNIMAX SUBMINIATURE SWITCHES

now in 5 TERMINAL STYLES



all integral with switch contacts

Flat, tinned lug with .058-inch hole. Just hook in end of wire, then solder.

Single-turret lug; made flat so wire won't slide around in assembly for soldering.

Double-turret flat lug — allows use of terminal as junction point.

Printed-circuit terminal; has hole for connecting component leads beneath wiring board.

Quick-Connect male terminal for snap-on wiring.

Write for catalog that gives details of UNIMAX subminiature switches.

UNIMAX SWITCH
Division, The W. L. Maxson Corporation
IVES ROAD, WALLINGFORD, CONNECTICUT

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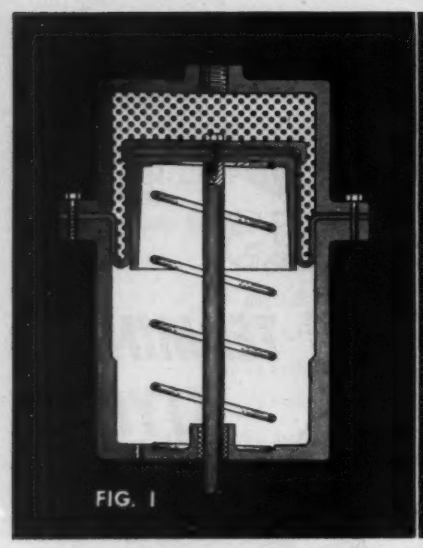
FIG. I

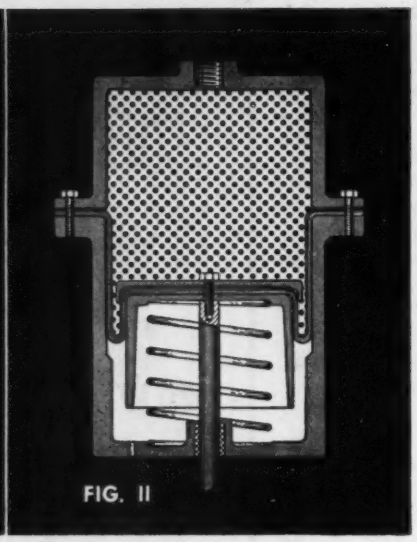
FIG. II

For Hydraulic and Pneumatic Applications

Nothing rolls like a Bellofram® Rolling Diaphragm. It's frictionless!

The Bellofram Rolling Diaphragm provides ultrasensitive response in hydraulic or pneumatic devices where frictionless, long-stroke action in small-diameter configurations is required . . . and where flex life of millions of cycles is necessary.

These desiderata are achieved through the *rolling* action of a flexible thin-sidewall diaphragm consisting of a high-tenacity fabric overlay embedded in elastomeric material.

Fig. I shows how Bellofram Rolling Diaphragm conforms to the piston. Fig. II shows how, as the piston descends under pressure, the diaphragm *rolls* off the piston's sidewall and onto the cylinder's sidewall in a smooth, continuous, frictionless movement.

The Bellofram principle can be applied widely in actuators, pumps, instruments, seals, accumulators, fluid dampers, etc.

Which of these advantages are you looking for?

To the designer confronted with situations for which conventional bellows, O-rings, or cup packings are inadequate, Bellofram Rolling Diaphragm offers a constellation of advantages found in no other product:

1. Friction-free (low hysteresis).
2. No break-out friction effects.
3. Completely leakproof device.
4. Constant area in all piston positions.
5. Almost infinite flex life (millions of cycles).
6. Sensitivity to extremely small pressure changes.
7. No mechanical spring gradient.
8. Compatibility with practically all environmental gases or fluids.
9. Automatic de-icing action.
10. Free positioning with complete relaxation at any point in its stroke.
11. Does not require close machine finish tolerances on pistons and cylinders.
12. Freedom from abrasive wear.
13. One hundred stock sizes. Four mounting configurations. Special types and sizes designed to order.
14. Excellent temperature stability, from —85°F. to 550°F. (from —120°F. to 700°F. in some cases).

Wide range of working pressures: 1 in. H_2O to 500 psi (up to 1200 psi in some cases).

Effective pressure areas from .028 to 108 sq. in.

Cylinder bore diameters from .25 to 12 in.

Extended range of stroke (.01 to 12 in.).

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BELLOFRAM CORPORATION, 8 BLANCHARD ROAD, BURLINGTON, MASSACHUSETTS

BRowning 2-2100 Mission 3-9000

Re-Usable Primary Batteries 185

A technical bulletin described a new silver-zinc battery system, which combines the features of both primary and secondary battery types, offering the highest energy output yet achieved; fast manual activation (full power in 5-30 minutes, with no bulky activation mechanism); long activated stand time; and recyclability. Because of these characteristics and their space and weight saving advantages, the batteries are particularly suited to the critical requirements. The 6-page brochure describes all electrical and physical characteristics; gives applications data; and compares performance with other battery systems through graphs and charts. Yardney Electric Corp., Los Angeles, Cal.

Permanent Magnets 176

Alnico VII which is an improved version of a grade of cast permanent magnets, has the greatest coercive force (1035 H_c oersteds, oriented) in the Alnico family. The new permanent magnet material is especially suited for core type meters and instruments. A new bulletin lists magnetic and material characteristics of the oriented and non-oriented forms and contains a demagnetization and energy product curve. Alnico VII A develops an energy value of 2.8 million (oriented). Indiana Steel Products Co., Valparaiso, Ind.

Precision Rotary Switches 126

Rotary switching devices for use in missiles and aircraft systems can sequence or switch circuitry as a function of time or of shaft position. Used in conjunction with sensitive realys or solid state switching techniques these units will handle high current loads. Similar to analog-digital converters in principle, these rotary switches eliminate the need for precise cam-like mechanical arrangement normally used in conjunction with a microswitch. Kearfott Co., Little Falls, N. J.

Electrical Contacts 134

4-page condensed catalog describes materials, properties, forms and uses of a line of electrical contacts. Discussed in the folder are contacts made from fine silver, coin silver, palladium, gold, platinum, special silver alloys and many powdered metal compositions. An outstanding feature is an outline showing best contacts for various applications. Gibson Electric Company, Delmont, Pa.

D-C Power 173

New specifications data on a series of high-precision, chopper-stabilized calibrators as well as an up-to-date coverage of a line of power supplies are included in a 12-page catalog. Featured is a discussion which is useful to an engineer concerned with instrumenting automatic delivery of d-c power in complex equipments. Electronic Measurement Co., Inc., Eatontown, N. J.

Flow Regulators 139

Pressure compensated hydraulic flow regulator valves have a simple and inexpensive integral servo using pressures up to 3000 psi without flow being affected by varying outlet pressures. Inline type construction permits easy installation. Its outside diameter is usually no larger than the hydraulic fittings used for connections. Government approved for aircraft installations and suited for missile and ground handline equipment. Waterman Engineering Company, Evanston, Illinois.

Variable Resistors 135

Dimensional drawings, tabular comparative data and complete technical description of new ½" diameter high temperature variable resistors using unique metal-ceramic resistance element, affording infinite resolution and better stability and higher reliability than presently available in carbonaceous type variable resistors. Chicago Telephone Supply Corp., Elkhart, Ind.

SIZE 8

SYNCHROS · SERVO MOTORS · MOTOR TACH GENERATORS

400 Cycle: Many for 125°C operation . . . Higher for special applications

Many Immediately Available From Stock in Small Quantities

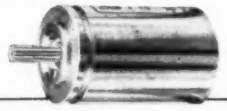
SIZE 8 SYNCHROS

Highly Stable. Minimum Error Variation from −55°C to +125°C

OSTER TYPE	CLASS	INPUT VOLTAGE	INPUT CURRENT AMPS	INPUT WATTS	OUTPUT VOLTAGE	PHASE SHIFT (° LEAD)	ROTOR RESISTANCE (OHM)	STATOR RESISTANCE OHMS	Z_{ro} OHMS	Z_{so} OHMS	Z_{rss} OHMS	NULL VOLTAGE (MV)	MAX. ERROR FROM E.Z. (MIN.)
4253-01*	LZ-CT	11.8	.087	.21	23.5	9.0	157.0	24.0	212+j722	28+j119	263+j69	30	±7
4269-01*	Diff	11.8	.087	.21	11.8	9.0	35.0	24.0	37+j139	28+j124	47+j13	30	±7
4273-01**	XMTR	26.0	.100	.54	11.8	8.5	34.0	12.0	48+j255	12+j45	82+j31	30	±7
4277-01*	HZ-CT	11.8	.030	.073	22.5	8.5	316.0	67.0	500+j1937	79+j350	594+j182	30	±7
4261-01**	Resolver	26.0	.043	.39	11.8	15.0	162.0	22.0	208+j612	34+j159	243+j77	30	±7

*Stator as Primary **Rotor as Primary

SIZE 8 SERVO MOTORS



OSTER TYPE	RATED VOLTAGES	Z = R + jX	IN. OZ. STALL TORQUE	RPM NO LOAD SPEED	WATTS PER PHASE	GM. CM. ROTOR INERTIA	LENGTH IN. MAX.	WEIGHT OZ.	T/I RATIO RAD/SEC²
5004-01	26V 26V	288 = 226 + j 176 294 = 238 + j 174	.15	6200	2.0	.47	0.863	1.2	22,500
5004-02	26V	288 = 226 + j 176	.-	----			0.863	1.2	22,500
							0.863	1.2	22,500
							0.863	1.2	30,000

TIO EC²	GENERATOR VOLTAGE	INPUT WATTS	OUTPUT VOLTS PER 1000/RPM
0	26	2.5	.25
0	26	2.5	.25

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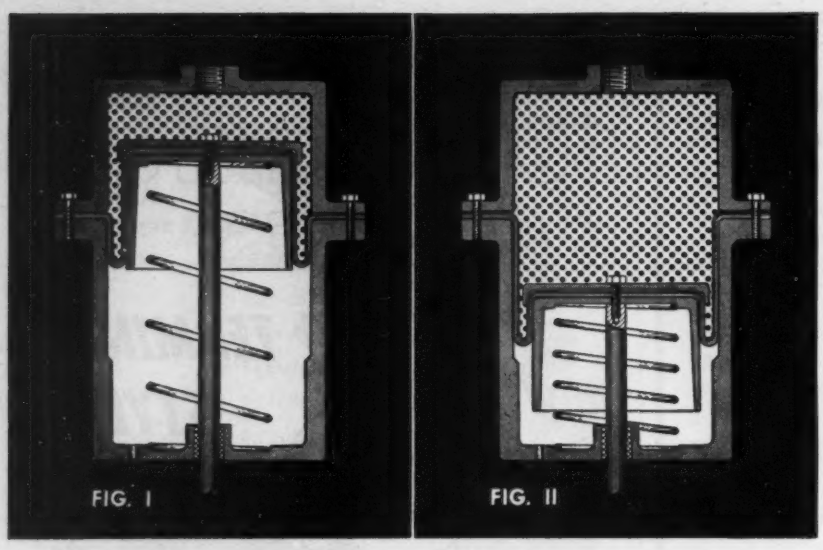

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These desiderata are achieved through the *rolling* action of a flexible thin-sidewall diaphragm consisting of a high-tenacity fabric overlay embedded in elastomeric material.

Fig. I shows how Bellofra
Fig. II shows how, as the
rolls off the piston's sidew
continuous, frictionless m

The Bellofram principle
instruments, seals, accum

Which of these a

To the designer confronted with situations for which conventional bellows, O-rings, or cup packings are inadequate, Bellofram Rolling Diaphragm offers a constellation of advantages found in no other product:

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4. Constant area in all piston positions.

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tions and suited for missile and ground handline equipment. Waterman Engineering Company, Evanston, Illinois.

Variable Resistors 135

Dimensional drawings, tabular comparative data and complete technical description of new ½" diameter high temperature variable resistors using unique metal-ceramic resistance element, affording infinite resolution and better stability and higher reliability than presently available in carbonaceous type variable resistors. Chicago Telephone Supply Corp., Elkhart, Ind.

SIZE 8

SYNCHROS · SERVO MOTORS · MOTOR TACH GENERATORS

400 Cycle: Many for 125°C operation . . . Higher for special applications

Many Immediately Available From Stock in Small Quantities

SIZE 8 SYNCHROS

Highly Stable. Minimum Error Variation from −55°C to +125°C

OSTER TYPE	CLASS	INPUT VOLTAGE	INPUT CURRENT AMPS	INPUT WATTS	OUTPUT VOLTAGE	PHASE SHIFT (° LEAD)	ROTOR RESISTANCE (OHM)	STATOR RESISTANCE OHMS	Z_{ro} OHMS	Z_{so} OHMS	Z_{rss} OHMS	• NULL VOLTAGE (MV)	MAX. ERROR FROM E.Z. (MIN.)
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4269-01*	Diff	11.8	.087	.21	11.8	9.0	35.0	24.0	37+j139	28+j124	47+j13	30	±7
4273-01**	XMTR	26.0	.100	.54	11.8	8.5	34.0	12.0	48+j255	12+j45	82+j31	30	±7
4277-01*	HZ-CT	11.8	.030	.073	22.5	8.5	316.0	67.0	500+j1937	79+j350	594+j182	30	±7
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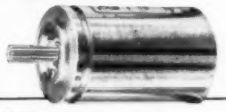

SIZE 8 SERVO MOTORS

OSTER TYPE	RATED VOLTAGES	Z = R + jX	IN. OZ. STALL TORQUE	RPM NO LOAD SPEED	WATTS PER PHASE	GM. CM. ROTOR INERTIA	LENGTH IN. MAX.	WEIGHT OZ.	T/I RATIO RAD/SEC²
5004-01	26V 26V	288 = 226 + j 176 294 = 238 + j 174	.15	6200	2.0	.47	0.863	1.2	22,500
5004-02	26V 36V	288 = 226 + j 176 526 = 409 + j 332	.15	6200	2.0	.47	0.863	1.2	22,500
5004-03	26V 40V	288 = 226 + j 176 715 = 582 + j 415	.15	6200	2.0	.47	0.863	1.2	22,500
5004-09	26V 40V	230 = 190 + j 131 519 = 399 + j 332	.20	6200	2.5	.47	0.863	1.2	30,000

SIZE 8 MOTOR TACH-GENERATORS

OSTER TYPE	RATED VOLTAGES	Z = R + jX	IN. OZ. STALL TORQUE	RPM NO LOAD SPEED	WATTS PER PHASE	GM. CM. ROTOR INERTIA	LENGTH IN. MAX.	WEIGHT OZ.	T/I RATIO RAD/SEC²	GENERATOR VOLTAGE	INPUT WATTS	OUTPUT VOLTS PER 1000/RPM
6204-01	26V 40V	230 = 190 + j 131 519 = 399 + j 332	.20	6000	2.5	.65	1.728	2.5	21,800	26	2.5	.25
6204-03	26V 26V	230 = 190 + j 131 230 = 190 + j 131	.20	6000	2.5	.65	1.728	2.5	21,800	26	2.5	.25

Oster®

The Size 8 400 Cycle Servo Motor Tach Generators listed above have 150° max. cont. frame temperature, 110 MA input current, ±5° phase shift and Null Voltage (Total R. M. S.) of 15 millivolts.

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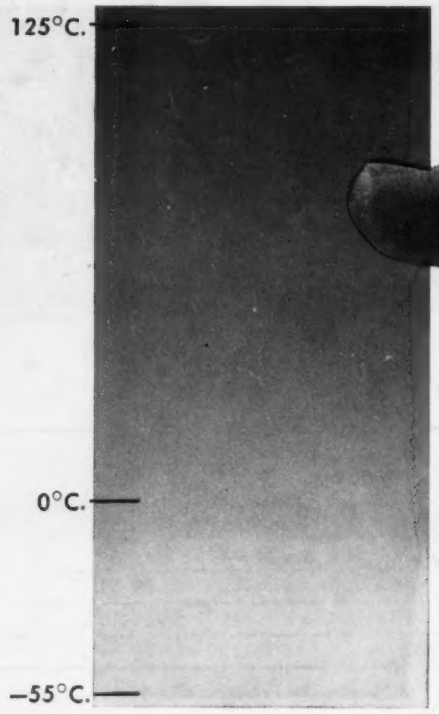
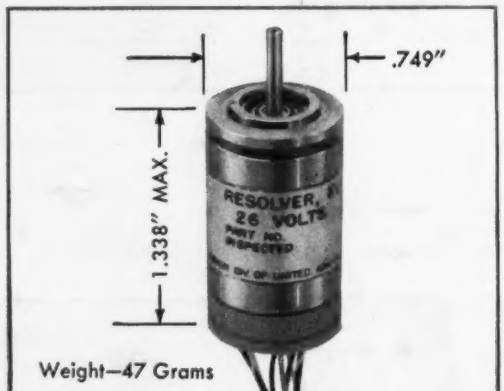


New size 08 Ket
over entire te

This new Ketay Resolver provides stability over th
entire temperature range of −55°C to +125°C. This
accomplished without the size and weight of compe
sating circuitry.

The Resolver has superior electrical characteristics

- **High Input Impedance**—almost twice that of an
existing unit.
- **Lower Phase Shift**—half that of existing units.



Weight—47 Grams

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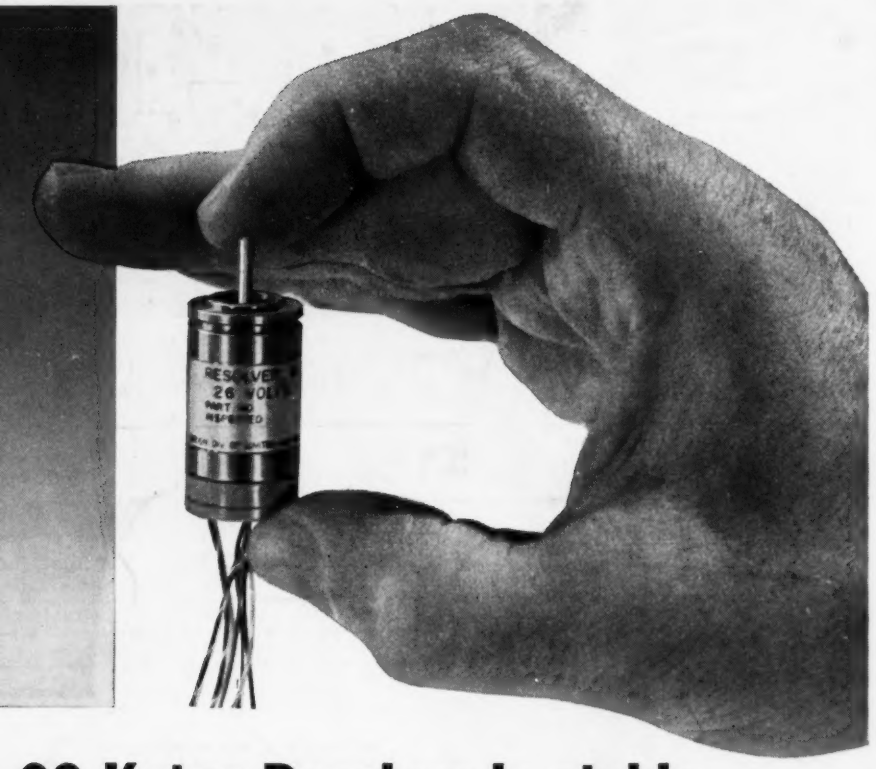

08 Ketay Resolver is stable entire temperature range

stability over the
to +125°C. This is
weight of compen-

cal characteristics:
twice that of any

f existing units.

749"

These features permit cascading twice as many resolvers with less degradation.

Resolver accuracy is now available in this small 08 size because of superior Ketay design. This Resolver meets or surpasses applicable military specifications for shock, vibration and humidity.

These typical specifications tell the story—

	At Room Temperature 25°C	MAXIMUM VARIATIONS Over Entire Temperature Range (Open Circuit) −55°C to +125°C
Input Impedance (ohms)	1010 ± 10% ∠79° ± 1°	± 10%
Transformation Ratio	1.059 ± 1%	± 1.0%
Phase Shift (lead)	6.0 ± 1°	± 2°
Null Voltage (total max.)	50.0 MV	± 15.0 MV
Rotor Interaxis Error (max.)	± 7′	± 2′
Stator Interaxis Error (max.)	± 7′	± 2′
Functional Accuracy (max.)	± 7′	± 3′
Frequency 400 cps		
Input Stator		
Number of Phases		
Rotor 2		
Stator 2		
Voltage Rating 26V AC		

Please write for detailed specifications and outline drawings.

KETAY DEPARTMENT

Norden Division of United Aircraft Corporation
Commack, Long Island, New York

CIRCLE NO. 84 ON INQUIRY CARD

ELECTRONIC COMPONENTS

New D. C. Power Source

A fail-safe power supply operated from a-c power is generally used where d-c power is needed which will be sustained if and when the a-c power is interrupted. It is also used for low voltage, high capacity d.c. reference voltage applications. The unit has an output voltage of 6.0 volts d-c, but by merely removing cells, other voltages of 4.8, 3.6, 2.4, and 1.2 volts d-c are available. Its total capacity is 450 milliamp-hours at a 10 hour rate without a-c. For extremely severe load conditions, it will supply 4 amps for short periods. Power input rate for charging purposes is adjustable to 0.006, 0.012, and 0.018 amps. Weight is 18 ounces, including cells, and the unit is approximately the size of an a-c outlet cover. If load conditions are such that the total drain is too high for one unit, it is possible to parallel several without alterations or adjustments. The power supply requires little or no servicing after installation and tests show that it can operate unattended for five years or more. American-Monarch Corp., Minneapolis, Minnesota.

Circle No. 260 on Inquiry Card.

Mesa Transistors

Because of unique design features, two newly-developed silicon mesa transistors have an unusually high small signal current gain. Either of the devices will replace up to three transistors of the same classification in many circuit applications. The new diffused junction, drift field mesa transistors (JEDEC No.'s 2N696 and 2N697) are designed for use as high speed switching units operating at medium power levels and as very high frequency amplifiers. A unique, U-shaped base-emitter configuration allows for the first time utilization of virtually all the transistor's emitter area. The minimum high frequency gain at high currents is 6 or more at 20 megacycles. This higher gain is due to tighter control of the base width in fabrication. The transistors are capable of useful current gains at 40 megacycles, indicating efficient operation in the ultra high frequency band when operated in a grounded base configuration. The photographic technique used in fabrication instead of conventional mechanical methods, gives greater precision of geometric control and results in better and exceptionally uniform characteristics. Hoffman Electronics Corp., L. A., Calif.

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Miniature Voltage Regulators

Transistorized regulator is designed to operate in ambients of −55 to +125°C and to meet MIL-E-5272. Available output voltages are between 35 and 150 volts d-c at load currents up to 500 ma. Regulation is 0.1% for input variations of ±20% and load variations from zero to full load. Models with 0.05% regulations are also available. The unit measures 2½ x 2½ x 2¾ in. and weighs 15 ozs. Power-tronic Systems, Inc., New Rochelle, N. Y.

Circle No. 142 on Inquiry Card

Switching Transistor

Designed to meet specification MIL-T-19500/67 (SigC), a new transistor has a 5 amp maximum current rating and a maximum collector-base voltage rating of 80 volts. The unit will readily dissipate 35 watts at 25°C mounting base temperature. Stringent environmental testing required by the specification assures the high reliability demanded in military applications. Bendix Aviation Corp., Long Branch, N. J.

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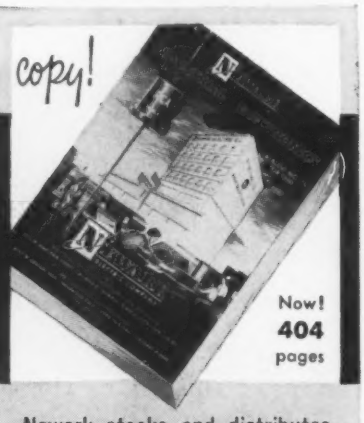

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